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Newton Lee
Editor

Encyclopedia of Computer Graphics and Games

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With 906 Figures and 116 Tables

Springer

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To all my students, past, present, and future!

Preface

The *Encyclopedia of Computer Graphics and Games* (ECGG) is an authoritative reference work covering the history, technologies, and trends of computer graphics and games catered to industry professionals and academic communities worldwide. The breadth and depth of topics covered by the encyclopedia benefit a wide diversity of readers including researchers, practitioners, teachers, and students who seek general as well as specific knowledge in computer graphics and games.

Los Angeles, USA — Newton Lee
November 2023

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Newton Lee is the founding president of the 501(c)(3) nonprofit Institute for Education, Research, and Scholarships based in Los Angeles, California, a former Disney and Bell Labs engineer, and a 2021 graduate of the FBI Citizens Academy.

Serving as an FBI Ambassador, Prof. Lee expounds on social media, campus safety, student mental health, cybersecurity, and counterterrorism as portrayed in the highly acclaimed Total Information Awareness book series published by Springer Nature. The Total Information Awareness trilogy has garnered rave reviews from *Newsweek*, *The Daily Beast*, *ACM Computing Reviews*, *AdWeek*, and *Choice Magazine*, among others. Veteran Staff Sergeant Andrew Price of the United States Air Force (USAF) remarked, "I am inspired by the prospect of world peace. I'd fully recommend following the author's steps, reaching beyond our borders, making friends outside our norm, and helping to foster world peace and a better tomorrow."

Prof. Lee has co-developed over 100 online games at The Walt Disney Company, and 12 bestselling and award-winning interactive titles including The Lion King Animated Storybook and Winnie the Pooh and the Honey Tree that were featured in the *Billboard* Magazine. He has also executive produced original songs that have played on American Idol and charted on US Billboard, UK Music Week, and US iTunes HOT 100 (Electronic).

He earned a B.S. and M.S. in Computer Science from Virginia Tech as well as an A.S. in Electrical Engineering and an honorary doctorate in Computer Science from Vincennes University. He has

been honored with a Michigan Leading Edge Technologies Award, two community development awards from the California Junior Chamber of Commerce, and four volunteer project leadership awards from The Walt Disney Company.

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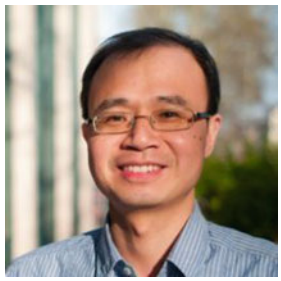

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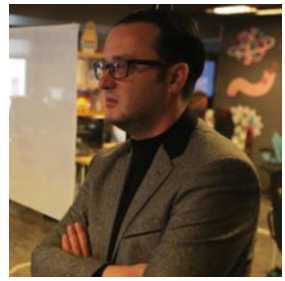

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A

2D Animation

▶ Pipeline of 2D Vector Animation in Television Series

2D Game

▶ Principle Structure to Create a 2D Game Level Editor

2D Game Engines

▶ Game Engine

2-Dimensional Animation

▶ Exploring Innovative Technology: 2D Image Based Animation with the iPad

2-Simplex Prism

▶ 2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making

2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making

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Tomsk State University of Architecture and Building, Tomsk, Russia

Synonyms

2-Simplex prism; Cognitive graphics tool; Decision-making; Geoinformation system; Intelligent dynamic system; Justification; n-simplex

Definition

The following definitions from the papers (Yankovskaya 2011; Yankovskaya et al. 2015a) are used:

A cognitive graphics tool (CGT) visually reflects a complex object, phenomenon, or process on a computer screen, enabling the users to form a new decision, idea, or hypothesis based on the visuals.

2-Simplex is an equilateral triangle.

3-Simplex is a regular tetrahedron.

2-Simplex prism is a triangular prism which has identical equilateral triangles (2-simplexes) in its bases.

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The height of the 2-simplex prism (Yankovskaya et al. 2015a) in intelligent dynamic systems corresponds to the dynamic process time interval under consideration. It is divided into a number of time intervals. The number of time intervals corresponds to the number of diagnostic or predictive decisions.

The distance between two adjacent 2-simpleces is proportional to the time interval between adjacent 2-simpleces.

In this case the distance between two adjacent 2-simpleces corresponds to the distance between two points on a map.

Learning axis is an independent direction of student evolution, e.g., theory knowledge level, ability to practical tasks solving, ability of electric circuit design, and research.

Test result is a set of coefficients, numerically representing the student's assessment achieved. Each coefficient corresponds to a particular learning axis.

Prediction result is a set of coefficients, numerically representing the student's assessment which he is likely to achieve in a preassigned time interval.

Introduction

Cognitive graphics tool (CGT) was developed as part of AI research in the 1980s of the twentieth century in the works of Pospelov (1992) and Zenkin (1991). A large number of CGT have been created and developed, including cognitive maps (Axelrod 1976), cognitive graphics system (Albu and Khoroshevskiy 1990), medical CGT (Kobrinskiy 1996), radar plots (Saary 2008), Chernoff faces (Raciborski 2009), the ternary diagram (Wang et al. 2012), 2-simplex (Yankovskaya 2011), and others (Yankovskaya et al. 2015a; Yankovskaya 2017). CGT allows representing the content of the object or process under investigation on a computer screen. CGT visually and clearly reflects the essence of a complex object (phenomenon, process) and is also capable of providing a fundamentally new decision (idea, hypothesis). An important feature of CGT is targeted influence on the intuitive imaginative thinking mechanisms.

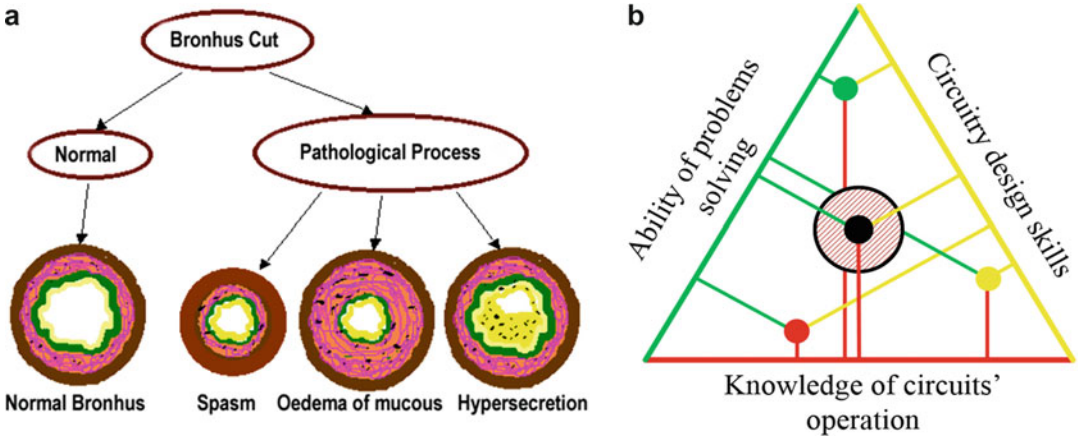
Cognitive graphics tools are used in a variety of intelligent systems for analysis of information structures of knowledge and data, revealing of different kinds of regularities in data and knowledge, and decision-making and its justification. Possible areas of application are medicine (diagnosis of diseases, treatment and preventive measures, rehabilitation of patients as well as solving organizational and managerial problems), education, geology, engineering, electronics, sociology, psychology, psychiatry, ecobiomedicine, ecogeology, etc. Dynamism represented by CGT can effectively reflect the dynamics of the patterns of objects under investigation in time.

Problem Background and Mathematical Basics of Intelligent Systems Construction

We suggest the following classifications of CGT by ways of representation (Yankovskaya and Galkin 2009; Yankovskaya 2011):

1. Naturalistic CGT, familiar graphic images of real objects. For example, visualization of tree data structure of pathological processes in bronchus (bronchial asthma, Fig. 1a).
2. Abstract CGT, CGT that does not have a mapping in the ordinary reality. For example, visualization of current level of students' knowledge by applying 2-simplex (Fig. 1b).

We use test pattern recognition to create the intelligent systems (Yankovskaya 2011), based on nontraditional (unusual) matrix method of data and knowledge representation; deep optimizing logic-combinatorial transformations in feature space; logic-combinatorial and logic-probabilistic, logic-combinatorial-probabilistic, and genetic methods of test pattern recognition; methods of complex decision-making; cognitive



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 1 Examples of naturalistic-based CGT (**a**) and CGT that does not have mapping in the ordinary reality (**b**)

2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 2 Matrix model for the data and knowledge representation

$$Q=\begin{array}{c}\begin{matrix}z_1 & z_2 & z_3 & z_4 & z_5 & z_6 & z_7 & z_8 & z_9 & z_{10} & z_{11}\end{matrix}\\ \begin{bmatrix}1&4&6&3&2&2&1&2&3&4&1\\4&4&5&2&3&2&7&8&3&4&1\\3&4&5&3&3&2&4&5&3&4&1\\3&4&4&1&4&4&2&3&1&5&1\\2&4&2&1&6&3&4&5&2&3&1\\2&4&5&1&3&-&4&3&1&2&1\\1&4&3&2&5&2&1&2&3&4&1\\3&4&2&2&6&2&2&3&3&2&1\\5&4&2&2&6&3&5&6&2&4&1\\4&4&6&1&2&5&5&6&1&4&2\end{bmatrix}\end{array}\begin{matrix}1\\2\\3\\4\\5\\6\\7\\8\\9\\10\end{matrix}\quad R=\begin{array}{c}\begin{matrix}k_1 & k_2\end{matrix}\\ \begin{bmatrix}1&2\\1&2\\1&2\\2&1\\2&1\\2&1\\1&3\\1&3\\3&2\\3&2\end{bmatrix}\end{array}\quad R'=\begin{bmatrix}1\\1\\1\\2\\2\\2\\3\\3\\4\\4\end{bmatrix}$$

means of decision-making; and justification of decision-making results.

We use unusual matrix model (Yankovskaya 2011) for the data and knowledge representation, example of which is given in Fig. 2.

$\boldsymbol{Q}$ – integer descriptions matrix.

$z_1, z_2, \ldots, z_{11}$ – characteristic features.

$\boldsymbol{R}$ – integer distinguishing matrix.

k_1, k_2 – classification features.

$\boldsymbol{R}'$ – one-column matrix whose elements are the numbers of patterns. Each pattern is associated with the final decision.

Rows of $\boldsymbol{Q}$ are mapped to objects from learning sample of a problem field.

Columns of $\boldsymbol{Q}$ are mapped to characteristic features, which describe each object.

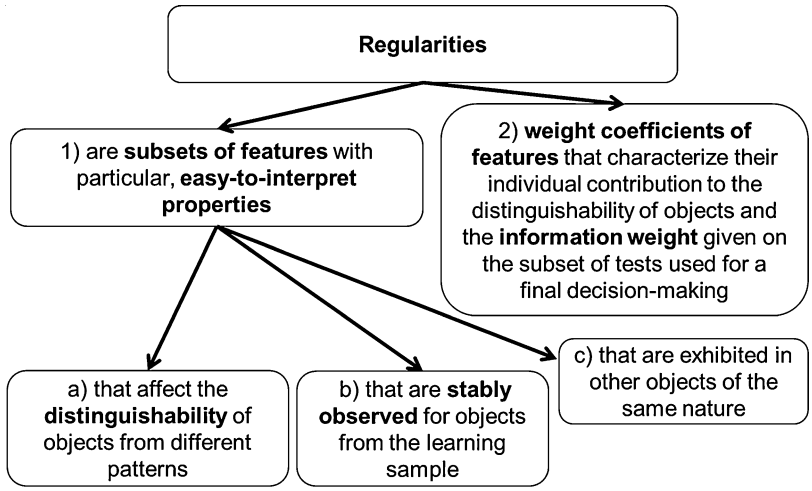
The element q_{ij} of the matrix $\boldsymbol{Q}$ determines the value j-th feature for i-th object if the value is defined and "–" if the value is undefined.

Each row of $\boldsymbol{R}$ is corresponded to the row of the matrix $\boldsymbol{Q}$ having the same index.

Columns of $\boldsymbol{R}$ are corresponded to distinguishing levels that represent classification features.

The set of all nonrepeating rows of the matrix $\boldsymbol{R}$ is compared to the number of selected patterns presented by the one-column matrix $\boldsymbol{R}'$.

The distinguishing matrices can be of three types (***R1***, ***R2***, and ***R3***). The rows of $\boldsymbol{Q}$ are put in correspondence with the rows of ***R1***, ***R2***, and ***R3*** and the levels of distinguishing (classification) features, with the columns of these matrices. ***R1***


Regularities
1) are **subsets of features** with particular, **easy-to-interpret properties**
2) **weight coefficients of features** that characterize their individual contribution to the distinguishability of objects and the **information weight** given on the subset of tests used for a final decision-making
a) that affect the **distinguishability** of objects from different patterns
b) that are **stably observed** for objects from the learning sample
c) that are exhibited in other objects of the same nature

2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 3 A block diagram of regularities definition

represents the included classification mechanisms. ***R2*** determines the sequence of actions which must be performed for each object. ***R3*** represents independent classification mechanisms corresponding, for instance, to the opinions of different experts.

The matrix of transition ***P*** (Yankovskaya et al. 2001; Yankovskaya 2011) is intended for the representation of dynamic knowledge about the investigated objects. Its rows are associated with the rows of ***Q***, and columns are associated with the instants (intervals) of time or control actions (Fig. 2).

The weight coefficients of the features characterizing their individual contribution to the distinguishability of objects from certain patterns (Yankovskaya 2011) and the information weight defined on the subset of tests used for a final decision-making (Yankovskaya 2011) with use the definition from Zhuravlev and Gurevitch (1990) is also regarded as regularities.

The following approaches are used when revealing regularities (Yankovskaya 2011): (1) with the construction of the irredundant matrix of implications; (2) with the partial construction of the irredundant matrix of implications; and (3) without the construction of the irredundant matrix of implications.

An irredundant matrix of implications ($\boldsymbol{U}'$) is constructed on the base of matrices ***Q*** and ***R*** and defines distinguishability of objects from different patterns (classes at the fixed mechanism of classification). The rows of $\boldsymbol{U}'$ are associated with characteristic features, and its columns, with the results of comparison of all possible pairs, pattern–pattern, object–pattern, and object–object, from different patterns.

A diagnostic test (DT) is a set of features that distinguishes any pair of objects that belong to different patterns and constructed on the base of irredundant implication matrix with application of logical-combinatorial algorithms (i.e., column coverings findings).

The DT is called "unconditional" if all features of the investigated object included in test are used simultaneously in decision-making process.

Decision-making on belonging of object under study to one or another pattern for every irredundant unconditional DT (IUDT) is performed out with use of threshold value of conditional degree of proximity of the object under study to the patterns.

Mixed DT (MDTs) present a new paradigm of development of intelligent systems based on test methods of pattern recognition (Yankovskaya 1996).

MDT is a compromise between unconditional and conditional components which are used for decision-making in intelligent systems as well as in blended education and training.

Respondent is a person participating in learning and testing.

Definition of a membership object x under study to pattern k is defined based on the coefficient of conditional degree of proximity (a_k) of object under study to the pattern (class) k, calculated by the formula (1):

$$a_k = \frac{S_k^x}{S_k},$$

where x – object under study

k – pattern (class),
S_k – coefficient of interclass similarity (similarity of objects inside the pattern (class)),
S_k^x – coefficient of similarity object x under study with pattern (class) k.

The rules for decision-making are constructed using coefficients of conditional degree of proximity a_i (Yankovskaya 2011).

Applied intelligent system is constructed on the base of intelligent instrumental software (IIS) IMSLOG (Yankovskaya et al. 2003). Purposes of IIS IMSLOG are formation of knowledge about objects in concrete problem or interdisciplinary area; regularities revealing in data and knowledge; decision rules construction on the basis of revealed regularities; recognition of object under investigation; and decision-making and its justification with CGT.

Mathematical Basis for Construction of Cognitive Graphics Tools

Theorem for the Construction of a Cognitive Graphics Tool n-Simplex

In 1991, Yankovskaya (1991), it was proposed using cognitive graphics tool 2-simplex for decision-making about object under investigation in the characteristic feature space to a certain pattern in intelligent systems for decision-making.

Theorem Suppose $a_1, a_2, \ldots, a_{n+1}$ is a set of simultaneously non-zero numbers where n is the dimension of a regular simplex. Then, there is one and only one point that following condition $h_1: h_2: \ldots: h_{n+1} = a_1: a_2: \ldots: a_{n+1}$ is correct, where h_i ($i = 1, 2, \ldots, n+1$) is the distance from this point to the i-th side (Yankovskaya 1991).

Coefficient h_i, ($i = 1, 2, \ldots, n+1$) represents the degree of conditional proximity of the object under investigation to the i-th pattern. The advantage is that n-simplex possesses the property of the constancy of the sum of distances (h) from any point to each side and the property of ratios preservation $h_1: h_2: \ldots: h_{n+1} = a_1: a_2: \ldots: a_{n+1}$.

The main function of n-simplex is a representation of an investigated object disposition among other objects of a learning sample (Yankovskaya 2011).

Construction of Cognitive Graphics Tools: 2-Simplex, 3-Simplex, and 2-Simplex Prism

We construct CGT 2-simplex and 3-simplex to visualize objects of 3 (4) patterns and the object under investigation using the formulas (1) given below.

For 2-simplex (3-simplex), distances h_1, h_2, and h_3 (h_1, h_2, h_3, h_4) are calculated on the basis of coefficients a_i and normalization operation from the following relations:

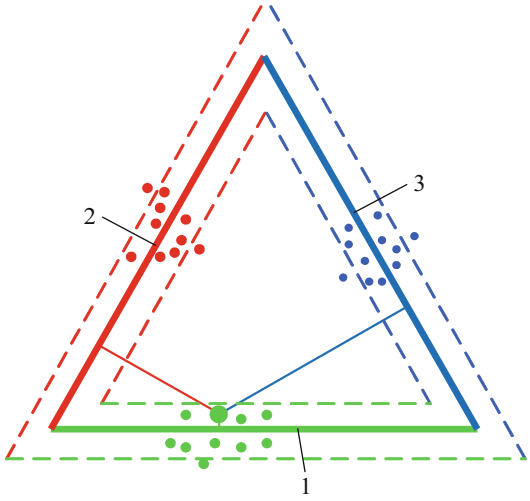
For 3-simplex distances h_1, h_2, h_3, and h_4 are calculated on the basis of coefficients a_i and normalization operation from the following relations:

$$\begin{cases} h = \sum_{i=1}^{4} h_i \\ h = \alpha \sum_{i=1}^{4} a_i \\ \frac{h_1}{a_1} = \frac{h_2}{a_2} = \frac{h_3}{a_3} = \frac{h_4}{a_4} \end{cases} \quad (1)$$

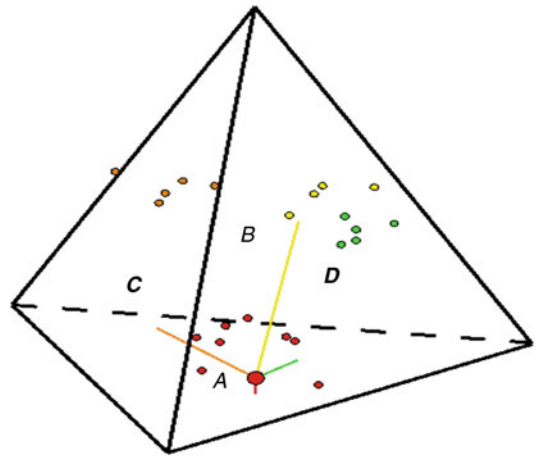
by the formula

$$h_i = \frac{h \cdot a_i}{\sum_{i=1}^{4} a_i} \quad (2)$$

Edges of 2-simplex (equilateral triangle edges), shown in Fig. 1b, are associated with three patterns (classes); the circle with big radius is the investigated object, and small circles are sample objects. Each pattern corresponds with some color. The distance from an object to a side is directly proportional to the object proximity to the pattern



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 4 2-Simplex with learning sample objects and the object under investigation



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 5 3-Simplex with learning sample objects and the object under investigation

corresponding to the side. The distance for the investigated object is displayed as color perpendicular lines to 2-simplex sides. Color of each line corresponds to the pattern color. An object color is mapped with an associated pattern (the nearest pattern or pattern determined by an expert.

We use dashed 2-simplexes to illustrate the accuracy of the pattern recognition on the Fig. 4.

The edges of 3-simplex, shown in Fig. 5, are associated with four patterns. We demonstrate in Fig. 5 the objects of four patterns (A, B, C, D) and the investigated object related to pattern A within 3-simplex. Objects related to pattern A are red, to pattern B are yellow, to pattern C are brown, and to pattern D are green.

The results of each of the diagnostic, predictive decisions are shown in the form of points in 2-simplexes disposed on cross sections of 2-simplex prism.

Distance from the basis of the prism to i-th 2-simplex h_i' corresponds to the fixation moment of object under investigation features, and it is calculated based on the following formula:

$$h_i' = H' \cdot \frac{T_i - T_{\min}}{T_{\max} - T_{\min}},$$

where H' – length of 2-simplex prism preassigned by a user and corresponded to the investigation duration

T_i – timestamp of features fixation of object under investigation for i-th examination

$T_{\min}$ – timestamp of features fixation of object under investigation for the first examination

$T_{\max}$ – timestamp of features fixation of object under investigation for the last examination.

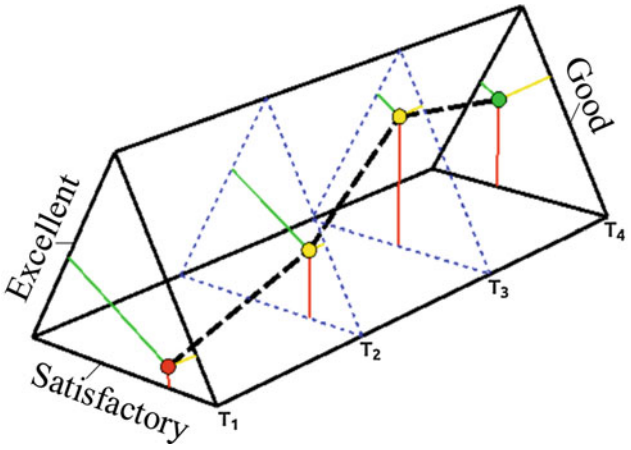
Since 2-simplex prism construction is based on 2-simplex, then the description of all 2-simplex objects is also correct for 2-simplex prism.

For intelligent geoinformation systems (GIS), the height corresponds to the distance from initial point to final destination. In this case the distance between two adjacent 2-simpleces corresponds to the distance between two points on a map.

Learning trajectory construction via 2-simplex prism is given in Fig. 6.

The edges of the 2-simplexes correspond to assessments satisfactory (red), good (yellow), and excellent (green).

We demonstrate learning path in the 2-simplex prism in Fig. 6. Height $\boldsymbol{H'}$ corresponds to time interval of learning, T_i ($i \in \{1, 2, 3, 4\}$).



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 6 Learning trajectory construction via 2-simplex prism cognitive tool

Software implementation of these models for intelligent system (IS) includes development of corresponded mathematical apparatus for transformation feature space to pattern space.

Using 2-Simplex Prism and 3-Simplex for Dynamic Diagnostic, Forecasting Processes and Dynamic Geoinformation Systems

Application in Learning-Testing Systems

Until 2015, we used 2-simplex and 3-simplex to make and justify decisions for dynamic processes visualization, modeling, and prediction (Yankovskaya 1997, 2011; Yankovskaya et al. 2003, 2015b; Yankovskaya and Semenov 2012). In 2015 we started to use 2-simplex prism for these purposes in various problem areas.

This section describes visualization of testing knowledge result in learning-testing system with estimation coefficients usage (Yankovskaya et al. 2016a, b, 2017a, 2018). In learning-testing system developed by us, respondent, after studying selected discipline, should pass MDT. During solution of this test, respondent actions map (RAM) is forming, which determines how well the respondent cope with different tasks based on the following abilities (skills):

1. Storage and reproduction of the material in unmodified form.
2. The reproduction of the material in modified form.
3. Extraction of new knowledge based on the studied material.
4. Problem-solving, etc.

It should be noticed that the different set of these parameters (a_1, a_2, a_3) can be transformed in same distances h_1, h_2, h_3 in case when sums of a_i for different sets are equal. So for that and similar cases, it is necessary to introduce the new parameter: a color saturation of point corresponded to the sum of a_i : $a_1 + a_2 + a_3$.

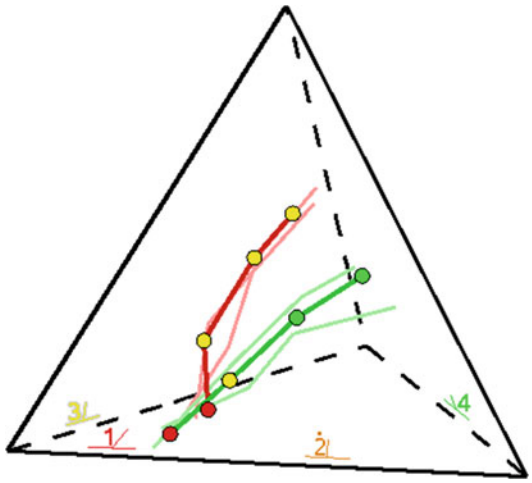
Example of 2-simplex prism usage for learning-testing systems is given in Fig. 6.

2-Simplex prism allows to represent dynamics for ability development of a respondent or a group of respondents. But it should be noticed that representation of test results of a big group of respondents with the usage of 2-simplex prism can be too complex and inconvenient.

Prediction of Students' Learning Results and Cognitive Graphics Tools for Its Visualization

We represent 3-simplex that visualizes dynamical process of learning and subdivides the respondents into two subgroups with close levels of learning abilities in Fig. 7.

One of the main research tasks is a fast creation of a simple prediction model prototype for a learning process. It allows to solve the following problems: (1) remove obstacles for solving other tasks



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 7 3-Simplex for dynamic processes cognitive visualization

of the current research; (2) get an estimation of an influence of learning process trajectory and its prediction visualization given for students on the speed of their learning; and (3) integrate a visualization library in the Web-based learning platform (Moodle). As a result, the main attention is focused on inputs and outputs of this model.

The prediction model has the following inputs: (1) a history of previous student testing results, which are obtained by MDT, described before, and (2) a time stamp of prediction. The output of the model is a predicted result which student should get at testing in preassigned time stamp.

Learning intelligent system (Yankovskaya et al. 2017b) is a good example of intelligent dynamic system. Control and prediction of students' learning results are the ones of the "hottest" problems in modern learning process. The respondents assess their results within a particular course module and explore the prospects for further intellectual development based on assignment performance and test results at each stage of learning cycle. The system implements the learning result prediction and suggests to students the next development directions: (1) research, (2) practical, (3) teaching, and (4) management activities.

We use 2-simplex prism to visualize and justify students' learning trajectories. The sides of prism correspond to the theoretical knowledge evaluation, skills to solve problems, and laboratory performance skills. A point in the space of these components at a particular time instant corresponds to the current evaluation of the above components combinations. In the process of learning, the point position can vary depending on the students' values correction. Preferably, this position should be within the tolerance area.

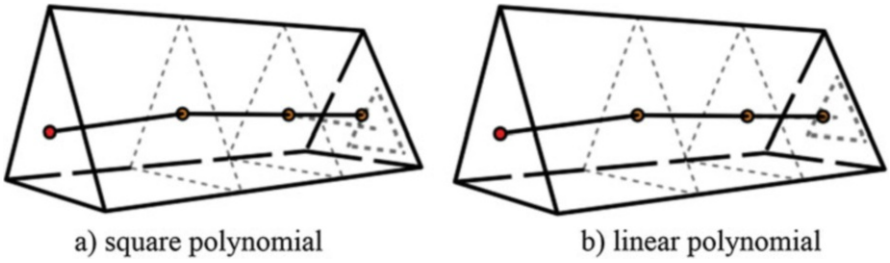
The prediction model has the following inputs: (1) a history of previous student testing results, which are obtained by MDT, described before, and (2) a timestamp of prediction. The output of the prediction model is a predicted result which student should get at testing in preassigned timestamp.

In the current research for a prediction, a simple extrapolation polynomial function is used. Polynomial degree p is configurable and can be used for its influence estimation on a prediction quality. For a polynomial function, the last $p + 1$ results of already performed tests by a student for each axis are used. A system of linear equations is constructed based on them and is solved via Gauss method. Confidence region prediction is calculated as delta between predicted and real result for the last performed test.

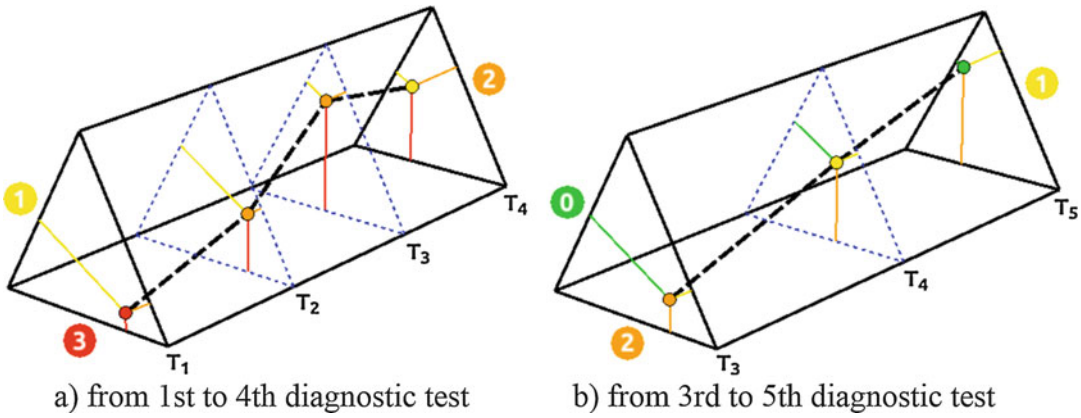
An example of student learning trajectory visualization and different prediction models is given in Fig. 8. By varying different models in the prediction process, it was found that for the majority of the respondents, the best prediction is achieved by using a linear polynomial model (the polynomial of the first power). In most cases this simple prediction model shows better quality of prediction than any other investigated model (using quadratic polynomial).

Decision Support for Diagnostics and Correction of Psychosomatic Disorders with Usage of 2-Simplex Prism

Diagnosis and intervention of organization stress with the usage of 2-simplex prism is another interesting example of CGT usage (Yankovskaya and Yamshanov 2016). The idea of diagnosis is based on a three-step diagnostics for each stage of organization stress (1, intenseness; 2, adaptation; 3, exhaustion) on the base of G. Selye conception. This scenario is interesting because there are four



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 8 Influence of the polynomial degree on the prediction quality



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 9 Results of diagnostic tests for organizational stress revealing using 2-simplex prism

patterns used (0 – for absence of organization stress) which is more that can be visualized and justified in 2-simplex prism. So two 2-simplex prisms can be used: one for the beginning of intervention (Fig. 9a) and another one for the ending of intervention (Fig. 9b).

The first test (T_1) reveals a level between the stage of exhaustion and the resistance stage and prepotency of the stage of exhaustion over the resistance stage. The second test (T_2) reveals that illness is decreasing from the exhausted stage (pattern 3) to the resistance stage (pattern 2). The third test (T_3) reveals that illness is decreased to a level between the resistance stage (pattern 2) and alarm stage (pattern 1). The fourth test (T_4) reveals prepotency of the alarm stage (pattern 1).

The second 2-simplex prism (Fig. 5) represents the transformation process from the resistance stage (pattern 2) to the absence of stress (pattern 0).

The fifth test (T_5) reveals the absence of the stress organization.

It should be noticed that the cognitive property of color is used in 2-simplex prism to represent dangerous diagnoses and patterns.

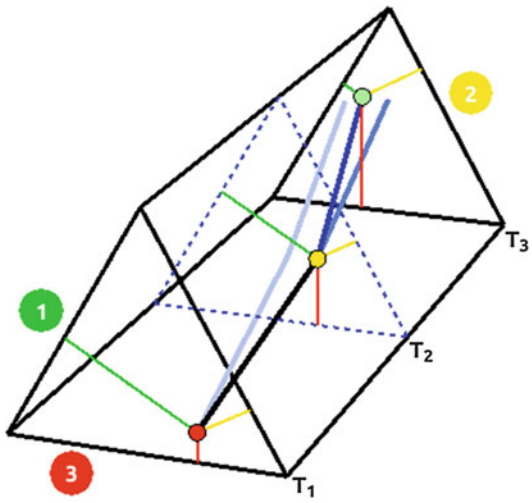
Cognitive Modeling

The cognitive modeling of a decision-making in the intelligent systems is one of the most important directions for creating intelligent systems (IS) in some priority areas of science researches and developing as medicine, psychology, sociology, environmental protection, energetics, systems of transport and telecommunication, control systems, etc. Manipulating some parameters of an object under investigation and using cognitive

tools of decision-making and its justifications in IS, we can perform a cognitive modeling based on the different kinds of knowledge representations.

An example of the modeling result on the base of prediction and therapeutic intervention with the use of 2-simplex prism (Yankovskaya and Yamshanov 2016) is presented in Fig. 10. After the first patient examination (T_1), the diagnosis is revealed – stage 3 (exhausted) of organization stress – and strategy of recovering is changed. With usage of mathematical model of a patient recovery process, it is possible to predict progress of patient recovery, which is shown in Fig. 10 as polyline of a light-blue color.

After the second examination (T_2), a progress of psychology stress recovering is diagnosed – organization stress is moved from stage 3 to stage 2 (resistance), but a real progress is worse than the predicted one. At this moment the doctor has two different strategies for continuation of recovering: purple and blue. The doctor uses this cognitive representation of different recovering strategies. He can choose one which gives the best result in the future. At this moment a strategy associated with a polyline of a purple color is more reasonable, because this strategy is applied to a patient. The model predicts full patient recovery until the moment of the next examination (T_3).



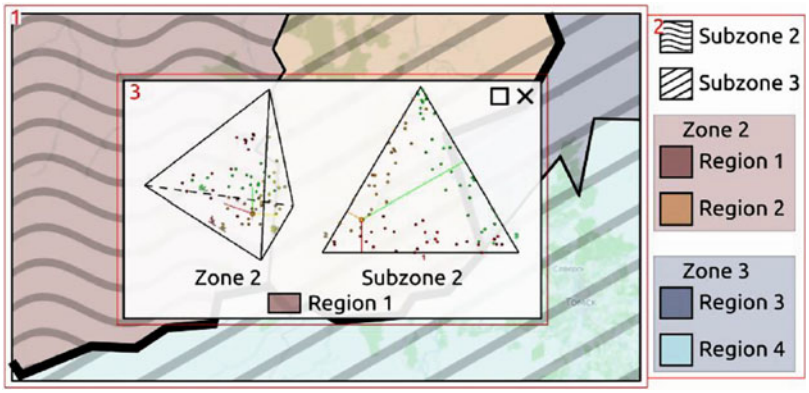
2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 10 Visualizing of a modeling result in 2-simplex prism

The cognitive modeling of decision-making is based on mathematical and computer methods with applying n-simplex family that allows optimizing a choice of influence of investigated object in accordance with a dynamical model of parameter change.

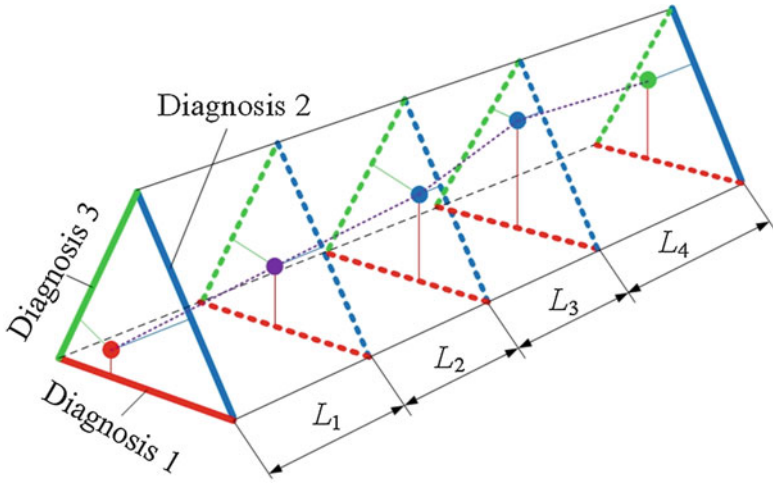
Using 2-Simplex Prism, 2-Simplex, and 3-Simplex for Geoinformation Systems

GIS (Ryumkin and Yankovskaya 2003) are widely applied practically in all spheres of human activity.

There are different scenarios for CGT usage in GIS. First common scenario is combination of ordinary reality objects (naturalistic CGT) and CGT, for example, map with real object and CGT overlay. Intelligent system of road-climatic zoning of territories (Yankovskaya and Sukhorukov 2017; Yankovskaya and Yamshanov 2014) is good example for this scenario. The free-distributed open-street maps with information layer overlay for the presentation of common information are used. Information layer presents road regions with borders and some information about its. This information is a number of zone and subzone which are determined for road region. A CGT for GIS visualization is presented in Fig. 11. Note that for the mapping of decision-making results with the usage of CGT, we use 3-simplex for the zone representation and 2-simplex for subzone representation in case when the number of subzones equals 3. The information layer is denoted by number 1. It is a transparent layer over the map. The thin black lines separate the different road regions. The different color tones are used for labeling the different zones (red color tone is used for zone 2; blue color tone is used for zone 3). Each color of the road region in every zone is unique color gradation from zone base color given from color transformation in the hue-saturation-bright palette (HSB palette). The wide black lines are used to separate the different zones. Hatching over road region shows subzone type. Only three hatching types are used and only two types from them presented in Fig. 11.



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 11 Visualization tool for representation of the map with zoning results



2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making, Fig. 12 Results of diagnostic tests for intelligent geoinformation systems. L_1, L_2, L_3, L_4 – distances between geographical points

Another interesting scenario of usage is the investigation of dependency of some object parameters on the base of distance from some point. It is also reasonable to use 2-simplex prism for decision-making and its justification in intelligent geoinformation systems (Yankovskaya 2017). An example of health problem diagnosis on the base of distance is given in Fig. 12.

Conclusions and Discussion

Cognitive graphics tool (CGT) is one of the directions of artificial intelligence which is reasonable to use for any problem solution. CGT described in the paper are efficient for decision-making and its justification for pattern recognition problem in big number of software systems.

The most important advantage for the information visualization in 2-simplex prism is the opportunity to analyze in dynamics the object under investigation. It allows users to make decisions, justify them, and analyze changes of object parameters.

The new approach to the prediction of students' learning results based on MDT and 2-simplex prism is examined. Simple prototype of the prediction model for a learning process is given. Specificity of confidence region visualization for CGT 2-simplex and 2-simplex prism are described. The mixed DT (MDT) tools were verified on third year students' test results of speciality "Electrical Power Engineering." Variation of prediction polinome degree shows that for the majority of students the prediction results obtained using linear polynome is better than that obtained using square polynome. On this

basis the following hypothesis can be formulated: the second derivative is not constant for a learning process and cannot be used for correct prediction.

A lot of intelligent systems constructed on the base of intelligent instrumental system IMSLOG (IIS IMSLOG) shows that CGT usage is very reasonable for big number of problem and interdisciplinary areas.

The research was conducted in such universities as Tomsk State University of Architecture and Building, Tomsk State University of Control Systems and Radioelectronics, Tomsk State University, Tomsk Polytechnic University, and (Tomsk State Pedagogical University.)

Cross-References

- ▶ Computer Graphics, Video Games, and Gamification Impacting (Re)habilitation, Healthcare, and Inclusive Well-Being
- ▶ Overview of Artificial Intelligence
- ▶ Teaching Computer Graphics by Application

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3D Animation Visualization

▶ Tabletop Storytelling

3D Avatars

▶ 3D Avatars in Virtual Reality Experience

3D Avatars in Virtual Reality Experience

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Synonyms

3D Avatars; Digital humans; Immersive technologies; Virtual reality

Definition

3D Avatar is a representation of human users in a Virtual reality environment. It represents the body of the user, interaction of the user with the surrounding environment, and other users in the virtual world to enhance the realism of the overall experience. It facilitates collaboration among various users and the virtual environment in multiplayer games, remote collaboration meetings, virtual events, immersive learning classes, and many such applications.

Introduction

Remote collaboration and remote interaction with peers are rising steadily due to their apparent advantages of cost-saving, convenience, and scalability. Immersive technology such as virtual reality transforms the remote collaboration experiences through its unique features such as presence and realistic interactions.

Virtual reality, typically called VR, is a simulation of a new environment with visuals and interactions created through computing devices. It can be achieved through specialized hardware such as a head-mounted device (HMD) and haptic controllers. Vision and spatial audio rendering by HMD and haptic feedback through controllers make the experiences feel real for users. Virtual reality replaces physical reality with computer-generated content. It achieves realism through information visualization, guiding the user, and making the environment interactive through mediums such as gestures, movements, and audio (Porter and Heppelmann 2017).

Immersion, presence, and interactivity are the characteristics of virtual reality which make it suitable for remote collaboration with other users in a simulated world. Immersion in a virtual environment is achieved by designing the surroundings and content around the user. Content formats such as 360-degree photos, videos, and computer-generated graphical environments make immersion possible and productive. Presence in a virtual environment for the user depends on the representation of the user and other users in the same virtual environment. 3D Avatars are one of the representation methods to create a feeling of presence for all the users. Interaction with the environment and other users is the most effective way to make the entire experience productive and enjoyable. Based on the capabilities of the VR HMD, the experiences could be noninteractive to highly interactive. One such feature is degree-of-freedom, allowing users to move in the virtual environment and change perspectives differently (Pangilinan et al. 2019).

Other immersive technologies such as Augmented Reality (AR) and Mixed Reality (MR) superimpose digital content on a user's view of the physical world. It is achieved through a handheld device such as a smartphone or specialized hardware such as Mixed Reality Glasses. AR or MR enhance the surrounding reality with digital content but do not alter the physical reality. The interactions in AR remain restricted mainly to the digital overlay on the surroundings; however, in VR, the interaction extends to the environment and other users. This difference creates a need to represent the users in a simulated VR environment, and 3D Avatars play a significant role in this interaction.

Virtual reality has several applications depending on the need for interactivity, immersion, and presence. Sectors such as gaming, education, manufacturing, healthcare, military, and real estate have seen a varied degree of adoption of VR for applications such as remote collaborations, live events, and immersive learning (Rao and Dawarwadikar 2020).

Many of these experiences are individual experiences where the simulation and interaction limit to only virtual environments. Examples of these experiences are simulation games, movie- viewing experiences, and immersive browsing applications. However, in several experiences, the interaction extends to other users who share the same virtual environment. Examples of these experiences are multiplayer games, social network applications, live virtual event applications, remote learning, and professional collaboration applications (Bredikhina et al. 2020).

Need for 3D Avatars in Virtual Reality

Avatar, in simple terms, is the representation of a player in a video game or artificially created virtual world. Technically, it could be as simple as a 2D shape or as complex as a realistic 3D model. An Avatar enhances the gaming experience by the player's ability to identify themselves with their avatar's visual and behavioral characteristics. This perception is significant in virtual reality applications where interaction with the environment and other users plays a crucial role (Wauck et al. 2018). Research shows the psychological significance of 3D Avatars in players treating their Avatar as an extended body in the virtual world. However, it depends on the experience

and the player's attitude toward the experience. Environmental and interactive feedback from other users also influences the immersive experience of users (Rosa et al. 2018).

3D Avatars can be created in multiple ways, such as 3D laser scanning, photogrammetry, and machine vision. With the help of 3D scanners or appropriate software tools, realistic 3D models can be created from as simple as a single photograph to as complex as a full-body scan (Berdic et al. 2017; Jo et al. 2017). There are broad categories of how Avatars are created and presented. There could be entirely imaginative Avatars that do not resemble the player. Cartoonish-looking Avatars can partially resemble a player. However, realistic Avatars could resemble the appearance of the player to a great degree (Čeliković et al. 2018). This broad range of realism of Avatar is used in various applications based on need. The players' perception of themselves enhances their ability to align themselves with their Avatar through customizations (Wauck et al. 2018). Realistic Avatars invoke the illusion of virtual body ownership characterized by acceptance control and change in behavior of the player in the virtual world. The uncanny valley (i.e., the relationship between Avatar and the emotional response) is characterized by humanness, eeriness, and attractiveness. The realistic Avatars help in realizing self-presence as well as the copresence of other players. Avatars help build rapport between players sharing the same virtual environment (Latoschik et al. 2017).

The systems to create configurable and customizable Avatars are technically complex and require a certain level of expertise for users to create them (Čeliković et al. 2018). The creation of an Avatar requires a lot of time and effort on the artistic and technical sides. The effort is assessed based on the need of the application. Research shows that there is little to no effect on player's performance in a virtual environment and player's subjective experience, based on the quality of their Avatar in the experience (Wauck et al. 2018).

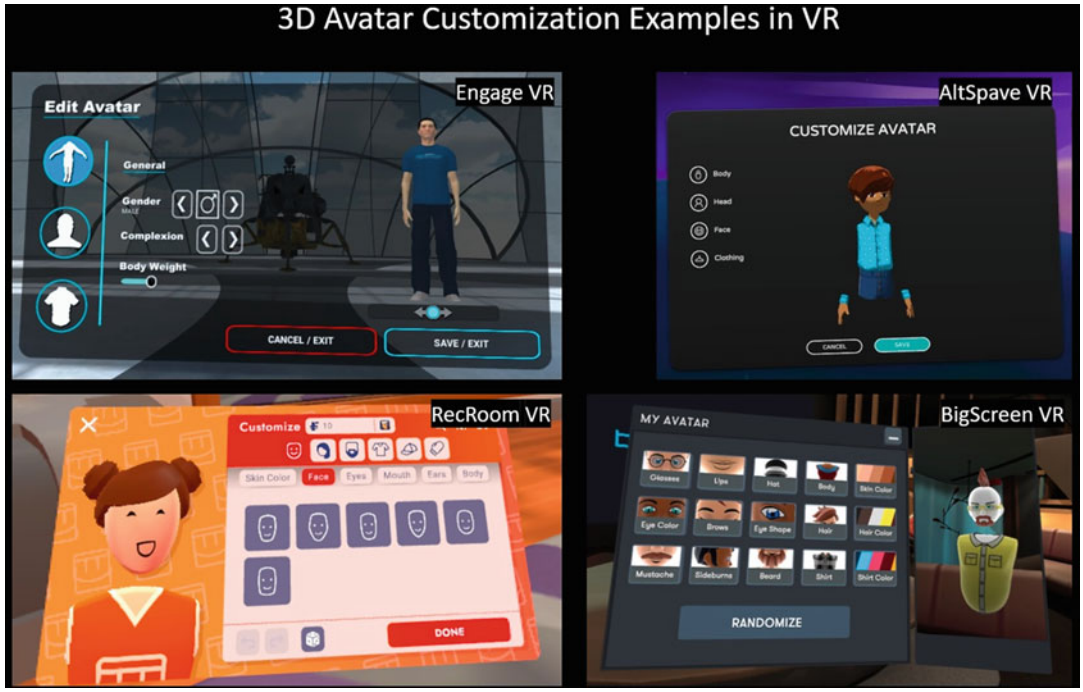
Virtual reality entertainment applications such as BigScreen allow multiple people to watch a movie in the virtual cinema hall. The interaction among the viewers happens through their Avatar movement, especially their head (tilting, nodding), body (changing places), and hands (waving, clapping). Oculus Venues or Oculus TV provides similar experiences to view an immersive stage performance while interacting with others. PokerStars VR and Racket Fury allow players to play Poker and Table tennis, respectively, with other online players. The interaction stays effective due to the use of synthetic Avatars. Social VR gatherings and events are available in AltspaceVR, VRChat, and RecRoom, where social groups can organize training, seminars, discussions, and many more such activities (Liu 2020).

What Makes an Avatar More Effective?

Presence – Avatar invokes body ownership among users, and research shows that presence is felt more effectively when players use a cartoon-like virtual Avatar that mimics players' outfits. Other possible ways to mimic player behavior are realistic Avatar created from photogrammetry of players and cartoon-like Avatars sketched by the artists (Jo et al. 2017).

Familiarity – Avatars feel most realistic to players when they are created with appropriate shapes and sizes mimicking the reality. Virtual body parts such as hands play a crucial role in VR experiences, and the appropriate size of hands and other objects play a critical role in creating realism (Ogawa et al. 2018). In some VR applications, the entire body of the Avatar is customizable, whereas, in some cases, only a partial body is visible and customizable. Figure 1 shows examples of 3D Avatar customizations available in some VR applications. Table 1 summarizes the customization options available for physical appearances in popular VR applications.

Expressions – Mimicking players' facial expressions on their Avatar strengthens the feeling of presence and interaction as nonverbal communication plays a significant role in human communication. Latest developments in hardware sensors and technology are accelerating the enhancement of Avatars through facial expression mapping in real time (Suzuki et al. 2017). While mapping players with Avatar's enfacement (similarity of player's face with Avatar's face)



3D Avatars in Virtual Reality Experience, Fig. 1 Examples of 3D Avatar customization in VR applications

3D Avatars in Virtual Reality Experience, Table 1 Comparison of VR applications for 3D Avatar customizations

Name of VR application	Avatar physical appearance customizations available			
	Body	Head	Face	Clothing and accessories
AltSpace vr	Body shape, skin tone, and nail polish	Hair, hair dye, hat, hat accent, and jaw shape	Eyebrows, eyes, mouth, nose, facial hair, and eyewear	Top, top accent, jacket, jacket accent, and bottom
Spatial VR	Body type (gender), skin tone			Shirt color
Engage VR	Body type (gender), skin tone, and body weight	Hair	Eyes, nose, and mouth	Tops, bottoms, shoes, and glasses
Oculus Venues	Body, skin tone	Hair	Face shape, face markings, and face lines	Eyewear, headwear, bindi, ear piercing, and nose piercing
RecRoom	Skin color, body	Face, hair style, hair colors, beard style, and beard colors	Eyes, mouth, ears	Clothing, shoulder, necklaces, belts, hats, glasses, earrings, and hand gloves
BigScreen VR	Skin color, body	Hair, hair color, moustache, sideburns, beard, and brows	Lips, eye shape, and eye color	Glasses, shirt, shirt color, and hat

and lip sync while talking enhance the embodiment significantly. Real-time communication with Avatars through speech using the onboard microphone of VR hardware also enriches interactions among players (Gonzalez-Franco et al. 2020).

Control – Avatar's sense of ownership is significantly influenced by self-control, i.e., controlling Avatar's movements and actions through the player's body movements. The player's point of view in a virtual environment (first-person view vs. third-person view) determines the realism of the Avatar for players interacting in groups. These factors often take precedence over the appearance of the Avatar alone (Fribourg et al. 2020).

Applications of 3D Avatars in Virtual Reality Experiences

Multiplayer Games

Games have been the most popular category of virtual reality applications since the launch of commercial VR headsets. In multiplayer games, interaction with the environment and interaction with other players are two distinct parts. For interacting with the environment, the embodiment and presence of hands play a pivotal role. Avatars do not influence perception much. However, in multiplayer games interacting with other players involves using Avatars to create the feeling of presence.

In role-playing games (RPG) such as rescue games, puzzle-solving games, or combat games, the realism of other players' Avatars enhances the feeling of presence, and own Avatar influences the players' social reputation. Often players choose their ideal self over their actual self while choosing customizations in the Avatar such as appearance, skin tones, and clothing (Wauck et al. 2018). Most fitness games and esports simulations, such as virtual boxing games, do not require full-body Avatars of the players as they project the first-person view to the players. The only Avatar of the opponent is considered relevant in such cases.

Professional Remote Collaboration

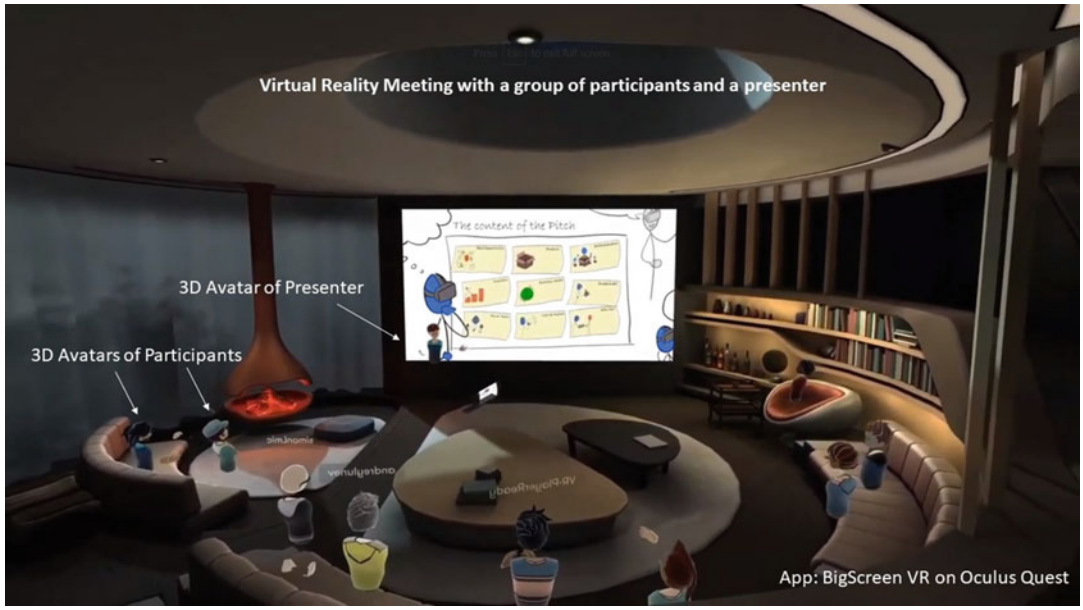
Remote collaboration at the professional level has increased over the last few years with various use cases. Utilitarian applications of virtual reality include remote maintenance support, virtual tours of factories, remote design/product reviews, and specialized applications such as remotely assisted surgeries. The feeling of presence expressed through 3D Avatars enhances the quality of the collaboration experiences, yet there are several areas of improvement. Generating realistic Avatars of multiple users, representing them in the virtual environment to identify them uniquely, and navigating the virtual environments without overlapping multiple Avatars at the same place are some of the challenges faced by current platforms such as VRChat, SpatialVR, and GlueVR (Liu 2020). Creating 3D Avatars professionally by scanning the user in 360 degrees surely enhances the usability and performance of professional collaboration applications (Kolkmeier et al. 2018) (Fig. 2).

Virtual Events

Virtual events are gaining popularity due to their cost and convenience benefits. Though VR hardware availability is the major hindrance in organizing large-scale virtual events such as conferences, stage shows, and live performances, the replacement of physical events into virtual events is on the rise. 3D Avatars and the feeling of presence in the virtual event venue provide an opportunity for participants to interact and network with fellow participants in events such as the entrepreneurship and innovation summit organized on the VirBELA VR platform (Jauhiainen 2021). The interactions among groups can range from attending a seminar or workshop to enjoying the after-event parties. Based on the situations, 3D Avatars and their realism play different roles in enhancing interactions. Additional factors such as virtual environment design and network speed for live experiences play a more significant role in overall user experience in such social events (Kreskowski et al. 2020).

Immersive Learning

Remote immersive learning has gained traction in the last few years, fueled by the availability of standalone VR hardware such as Google Cardboard and Oculus Quest. VR solutions and apps


Virtual Reality Meeting with a group of participants and a presenter
3D Avatar of Presenter
3D Avatars of Participants
App: BigScreen VR on Oculus Quest

3D Avatars in Virtual Reality Experience, Fig. 2 Virtual reality group meeting with 3D Avatars of the users (App: Big Screen VR on Oculus Quest)

intercepted learnings at various levels, such as professional, personal, and academic, and various age groups such as schools, colleges, and corporate training. Professional skills such as technical skills and design skills can be taught in an immersive virtual environment facilitated by virtual instructors and the presence of other classmates remotely. During such interactions, Avatars of participants play a pivotal role in engaging in the learning experience. Hand movement, head movement, and voice interactions make the group- learning experience engaging. Personal skills such as public speaking are possible on a virtual stage with a simulated audience created through 3D Avatars. Such virtual learning experiences enhance motivation as well as the understanding of the learners (Gomes de Siqueira et al. 2021).

Limitations of 3D Avatars

Though 3D Avatars are an excellent way of representing humans in the virtual world, and there is a varying degree of realism available today technologically, we are still far away from the realism that matches the cinematic quality of characters. The costs and effort involved in improving the realism and features of a 3D Avatar are disproportionate to the benefits at the consumer levels; hence, most VR applications still use synthetic or cartoonish Avatars, which are widely accepted in current applications. So far, creating a realistic Avatar from a user image is the most popular and cost-effective technique. The alternate to 3D Avatars is holographic projections, which can simulate the humans' appearance and their realistic size and expressions. Technology for holographic projections and superimposing real human wrappers to create realistic cinematic characters is developing rapidly and will be incorporated into virtual worlds soon (Balamurugan 2017).

Conclusion

3D Avatars play an essential role in virtual reality experiences while interacting with other users and occasionally with the environment. Though the

technology to create realistic 3D Avatars is not fully mature and cost-effective, some workarounds are widely adopted across VR solutions. Depending on the experience, full-size body Avatars or only specific body parts such as hands or heads are used in VR experiences. VR users' presence and immersive experience largely depend on their perception of themselves in virtual Avatar and their social reputation, influencing their customization choices. As more and more social experiences and new-age VR hardware penetration are increasing, the need to develop 3D Avatars is growing over the last few years. However, alternates such as virtual humans projected through holographic projections will replace most synthetic 3D Avatars in the long run.

Advances in other technologies such as artificial intelligence, networks (5G/6G), and processing hardware (GPUs) will fast track adoption of realistic Avatars in VR experiences.

Cross-References

- ▶ Immersive Visualizations Using Augmented Reality and Virtual Reality
- ▶ Player-Avatar Link: Interdisciplinary Embodiment Perspectives

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3D Board Game

▶ Augmented Reality Ludo Board Game with Q-Learning on Handheld

3D Game Asset Generation of Historical Architecture Through Photogrammetry

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Synonyms

Asset creation; Cultural heritage; Digital preservation; Game assets; Image-based modeling

Definition

Photogrammetry is the method of generating accurate photorealistic 3D models through organized assortments of photographs. Typically, photogrammetry is associated with the making of maps from aerial photographs but when the same system of algorithms are applied to documenting a 3D object, it can be used to create photo accurate 3D models of any building, object, or landscape desired.

3D assets in game-building refer to the three-dimensional models that the game employs as objects; the assets can range from stones to mountains, bricks to monuments. They can include every 3D object that can go into a game.

Introduction

A large spectrum of domains like video game production, virtual reality simulations, and augmented reality applications make intensive use of 3D-generated assets. There are many graphics suites that already offer a large set of tools and functionalities to manage the creation of such content, although they are usually characterized by a steep learning curve.

In games, the use of photogrammetry can enable the developer to build 3D objects that can be developed to look close to the original. Game developers have already adopted the method of photogrammetry to develop game objects and this entry highlights its use to accurately recreate historical representations in-game.

Resources Required for Photogrammetry

As photogrammetry uses images as input data to generate these models, hardware to record images like a handheld camera or a phone camera is mandatory to the process. Other requirements to generate models from photos are the image stitching software like Trimble Inpho, Reality Capture, Pix4D, AliceVision Meshroom, Agisoft Photoscan, and more. A few of these software, for example, Reality Capture, can take photos as well as videos as input data. Recently, software like Trnio and Sony 3D Creator allows the user to scan and produce 3D models with a smartphone as well.

After the model is generated, modeling software like Blender can be used to refine it by editing out any extra unwanted meshes or by making up for incomplete data. Following that, mesh manipulation software like ZBrush can be used to reduce the mesh count of the 3D object so that it becomes functionally lighter while retaining its visual aesthetics and intricacies.

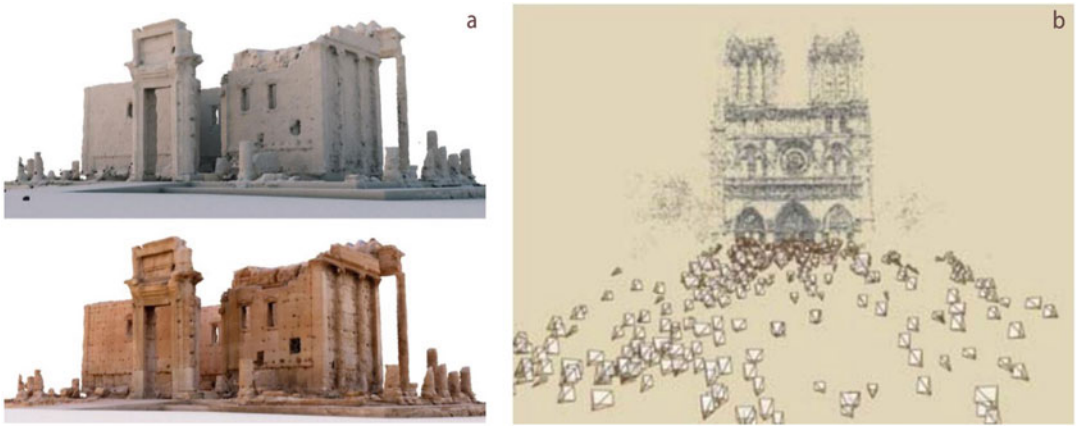
Digitizing Cultural Heritage Through Photogrammetry

In a study by Yilmaz and team (2007), the researchers reported on a two-story building that had burnt down twice and the conservation office of Turkey had needed to reconstruct the building through a restoration project. There happened to be no documentation available in the form of drawings or measurements as a reference to go ahead. Photogrammetry was then used to document the building holistically and re-photographed after the second fire to note the changes in the physicality of the structure. After processing the images in the photo-modeling software, architectural drawings could be obtained through the 3D model produced. With the help of the drawings, architects were able to estimate the three-dimensional measurements of the original building and with that, they were able to restore the building back to its original form (Yilmaz et al. 2007). This achievement of digitally countering architectural wear and tear can help games in employing photogrammetry to complete or re-create parts of worn down monuments into their original pristine condition for enhanced immersion.

Wahbeh et al. (2016) in their study go as far as to show that historical architecture, if well photographed even by tourists, can be recreated digitally using the available database online and some panoramic image-based documentation. Their research exploits the potential of multi-image reconstruction to model the destroyed temple of Bel, one of the heritage monuments of Syria (Wahbeh et al. 2016), see Fig. 1a. This is also in line with the image-based modeling system presented by Snavely et al. (2006) in their research, where they were able to interactively browse and explore large unstructured collections of photographs of a scene using a novel 3D interface. Their image-based modeling system could then produce a 3D model rendered solely from these collections of unstructured images, mainly retrieved from the Internet (Snavely et al. 2006), shown in Fig. 1b.

Using Cultural Heritage In-Game

A famous recent example of preserving a culturally important monument through digital documentation in a game is that of the burning of the Notre Dame cathedral in Paris. Built-in a gothic French architectural style, the construction was first started in the twelfth century and was not finished until 1345. In 2019, the cathedral became a victim of a fire breakout that damaged a significant part of its architecture. However, between 2010 and 2014, Ubisoft, a company that makes digital games, had intensively mapped the entire



3D Game Asset Generation of Historical Architecture Through Photogrammetry, Fig. 1 (**a**) Photogrammetric modeling of the "Bel" Temple in Syria. (Source: Wahbeh et al. 2016); (**b**) Photogrammetric modeling of a heritage building using large data sets of unorganized images. (Source: Snavely et al. 2006)

monument in an effort to recreate it in their game "Assassin's Creed Unity" (Elbaz et al. 2020). This indicated positively that historical monuments could play a huge role in level design in games.

This is in line with Statham's (2020) finding that models based on image-based modeling can be used in digital games as assets. The study also revealed how many of the major commercial games had also started employing photogrammetry at a large scale in an effort to render the game environment as close to real-life as possible (Statham 2020) (Fig. 2).

Conclusion and Discussion

The photogrammetric digitization of cultural heritage is a noninvasive method to preserve and archive historical monuments and sites. Although photogrammetry has been adopted by the gaming industry to provide for realistic landscapes and objects, it can also be used to authentically recreate historical sites and landscapes. Using this method also ensures that the intricacies of art objects are not lost due to their complexities as photogrammetry offers a more honest recreation when compared to 3D modeling. It has also shown to help experts recreate old monuments even when they have been the subject of partial wear and tear.

The methods of photogrammetry can also be applied to creating a true-to-reality environment around the monuments. The landscapes can be scanned thoroughly by imaging the surrounding objects like rocks, pillars, trees, etc., and they can then be rendered into photogrammetric models (Davis et al. 2017; Statham 2020). This can increase the authenticity of the digital recreation many folds and greatly help with level and environment design in-game as currently there is observed to be a lack of diverse environmental assets available that are representative of varying geographies.

It is also pertinent to observe and follow all the local and national laws that the structure falls under. In many countries, flying a camera mounted drone near a culturally important monument is not allowed. The process of

3D Game Asset Generation of Historical Architecture Through Photogrammetry, Fig. 2 3D Modeling of the cathedral of Notre Dame in the game Assassin's Creed Unity. (Source: https://news.ubisoft.com/en-us/article/2Hh4JLkJ1GJIMEg0lk3Lfy)

documentation and the following usage of the digital version of the monuments in-game can be prone copyright infringements and other violations and should be taken care of accordingly.

Cross-References

► 3D Modelling Through Photogrammetry in Cultural Heritage

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3D Game Engines

► Game Engine

3D Interaction

► Virtual Hand Metaphor in Virtual Reality

3D Modelling Through Photogrammetry in Cultural Heritage

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Synonyms

Photogrammetry; Terrestrial Photogrammetry

Definitions

Photogrammetry is a technique for estimating the exact position of surface points of an object by using multiple photographs. Aerial photogrammetry is based on the acquisition of photographs of a certain area from the sky, commonly by placing cameras on a plane, drone, or even a satellite, to create a topographical map or terrain model. Terrestrial photogrammetry aims at taking 3D measurements of an object, using photographs of that object taken from a camera positioned on the surface of the earth. Terrestrial photogrammetry is also referred to as close-range photogrammetry when the photographs of the object are taken at a close range.

Introduction

Photogrammetry is a manual process which requires in-depth understanding since it involves several aspects; for instance, the focal length and position of the camera when taking each photograph will impact the quality of the end result. However, recent technological advancements (increase of computational power, release of affordable, yet powerful, digital cameras, etc.),

along with the availability of free, user-friendly software, have simplified the process of photogrammetry. Combined with high-quality companion software, digital close-range photogrammetry is heavily used for the 3D digitization of cultural heritage.

The most widespread photogrammetry method for creating 3D models of real objects is based on structure-from-motion (SfM). SfM involves the provision of overlapping images of an object, captured from multiple viewpoints (see Fig. 1). Important data, such as the camera's position and orientation, are automatically calculated by specialized software, which also facilitates the 3D model creation and texturing process, extracting information directly from the set of overlapping images (Westoby et al. 2012).

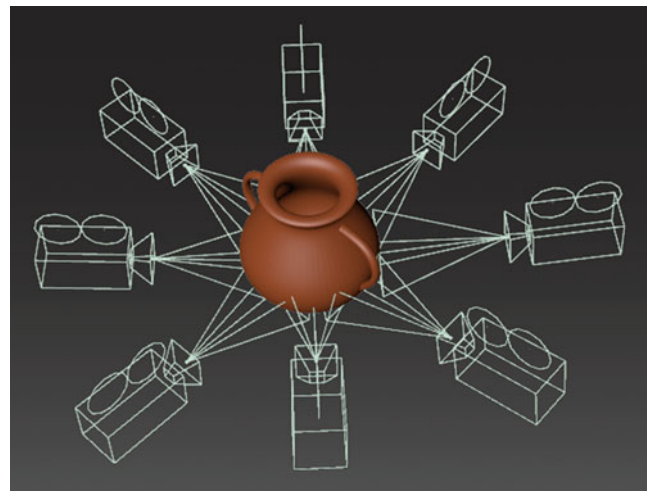
3D Digitization of Cultural Heritage

The 3D digitization of cultural heritage is a common practice for the generation of 3D models used for exhibition, conservation, and protection, 3D printing-based replication, dissemination through web and mobile application channels, digital restoration of damaged parts, and monitoring of overtime alterations (e.g., when cultural assets are exposed to open environment) (Pieraccini et al. 2001). The 3D digitization process is tailored according to physical dimensions; thus, monuments and archaeological sites are digitized with the use of topographic techniques and aerial photogrammetry, whereas close-range photogrammetry is a better-suited, cost-effective 3D digitization solution for smaller-scale objects (Pavlidis et al. 2007).

Using Photogrammetry to 3D Digitize Cultural Heritage

Several studies document best practices and demonstrate the advantages of employing either close-range or aerial photogrammetry for the 3D digitization of cultural heritage. Some of these advantages are high accuracy of the produced 3D models and improvement of the safety factor during the digitization of hazardous or inaccessible areas (Remondino et al. 2005; Yilmaz et al. 2007; Fassi et al. 2013).

Santagati et al. (2013) provide an example of close-range photogrammetry in cultural heritage documentation, describing the 3D digitization process of a small chapel using Autodesk 123D Catch (recently rebranded to Recap https://www.autodesk.com/products/recap/), a widespread, cloud-based, free photogrammetry software (see Fig. 2a and b). The study revealed that close-range photogrammetry requires short



3D Modelling Through Photogrammetry in Cultural Heritage, Fig. 1 Multiple overlapping photos of an object acquired for SfM photogrammetry

3D Modelling Through Photogrammetry in Cultural Heritage, Fig. 2 (**a**) Chapel; (**b**) the chapel's 3D model created using close-range photogrammetry. (Source: Santagati et al. 2013); (**c**) the Clifden Castle in Ireland; (**d**) the Clifden Castle 3D model created using aerial photogrammetry. (Copyright: Pix4D - Measure from Image)

image processing times while offering high accuracy and quality even when nonprofessional cameras are used. Moreover, the metric accuracy for small objects (e.g., statures) is in the order of *mm*, while for medium to large objects and architectural buildings, it is in the order of *cm*.

On the other hand, aerial photogrammetry can be used to accurately digitize monuments (Grussenmeyer et al. 2008). An example is shown in Fig. 2c and d, where a castle's 3D model has been produced using photographs taken with a camera mounted on a drone, thereafter fed to a popular aerial photogrammetry software, Pix4Dmodel https://pix4d.com/product/pix4dmodel/.

Even if photogrammetry appears suitable for 3D cultural heritage digitization, it does not come without limitations. The most common ones are the long processing times to attain high accuracy (Fassi et al. 2013), the requirement of software products for structured photo datasets (Santagati et al. 2013), and the holes found on 3D objects when the physical object is not properly photographed (Remondino et al. 2005).

Conclusion

The 3D digitization of cultural heritage may be carried out through the manual creation of 3D models, by analyzing architectural plans, or via automated methods, such as laser scanning and photogrammetry. Even though there is an ongoing debate regarding comparative advantages of photogrammetry to laser scanning and vice versa, for 3D digitization in cultural heritage, complementary application of methods is considered as the most appropriate solution for digitization projects (Grussenmeyer et al. 2008).

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3D Object Manipulation

▶ Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design

3D Pointing

▶ Raycasting in Virtual Reality
▶ Virtual Pointing Metaphor in Virtual Reality

3D Printing

▶ Tactile Visualization and 3D Printing for Education

3D Printing, History of

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Synonyms

Additive manufacturing; Direct digital manufacturing; Rapid manufacturing; Rapid prototyping; Solid-free form technology

Definitions

3D Printing is a form of manufacturing that adds materials together in layers to form an object. This is in direct contrast to subtraction manufacturing, which cuts away at a material to form an object. Primarily using plastics and/or metal, this form of manufacturing is rapidly developing and handling new, exotic materials. Its increasing adoption rate will have a big impact on the processes of distribution and production.

Introduction

Beginning in the 1980s, this technology has had an interesting development as it has reached its more mainstreamed status. The individuals that contributed to this interesting industry are varied across the globe. First being referenced as Rapid Prototyping, this industry donned the title "3D Printing" in the 1990s and has slowly become an almost ubiquitous household term today.

The History of 3D Printing

The 1980s is known for its retina-burning bright spandex pants, go-go dancers, and massively teased hair, but lesser known is the fact that it was the same decade that 3D printing was born. It flew under the radar of the public for several decades in almost complete obscurity as it

incubated. During that time they were more often to fall under the title of Rapid Prototyping (RP) technologies. Actually, 3D printing is interchangeable with quite a few terms. There is the previously mentioned Rapid Prototyping but there is also Rapid Manufacturing (RM), Additive Manufacturing (AM) technologies, Solid-Free Form technology (SFF), or Direct Digital Manufacturing (DDM).

What is so fundamentally different about 3D printing is that it uses an additive manufacturing approach, which is where precise amounts of materials are bound together in exact layers to form an object, versus the conventional subtractive manufacturing method, which removes materials to create products. Much like the varied titles that can be referenced to this form of manufacturing, so too are the hands that formed it. The history of 3D Printing is varied and expands the narratives of some very eclectic people.

Hideo Kodama of Nagoya Municipal Industrial Research Institute published the first working account of a photopolymer additive manufacturing system in 1981 (Tomioka and Okazaki 2014). Mr. Kodama's inspirational moment struck him over a year earlier while he was riding a bus home, reflecting on an exhibition in Nagoya where he was able to observe a machine capable of making letters utilizing liquid resin applied to a glass surface. The machine he witnessed at work was targeted towards the newspaper industry; however, upon reflection Kodama realized that he could harness this to create three-dimensional objects and began work on his concept (Tomioka and Okazaki 2014).

It was in early 1980 that he set off to work applying what he saw at the exhibition to a new way of creating items. After a viable system was brought to fruition, he began to show his peers his innovative concept while starting the process of filing a patent; however, without the interests or support of his peers, doubt soon overcame him and he quietly disregarded the effort. In a regrettable move, he did not complete a review period necessary for receiving the patent. Kodama is said to have created a two-story miniature house the size of a human palm by manipulating thin layers of resin; impressively, the 3D model held rooms, a spiral staircase, and even a dining room table (Tomioka and Okazaki 2014). Despite his tremendous personal success with the concept, Mr. Kodama felt disheartened and thought his concept was nothing more than a novelty, rather than the beginning of something revolutionary. Reflecting now, he says that: "I should have worked harder to make people understand the significance of my research results"(Tomioka and Okazaki 2014).

Other individuals, Alain Le Mèhautè, Olivier de Witte, and Jean Claude Andrè, filed a patent in 1984 on the Stereolithographic process but was abandoned by the French General Electric Company (now Alcatel-Alsthom) and CILAS, a subsidiary of the European Aeronautic Defense and Space Consortium for a "lack of business perspective" (Mendoza 2016). It seemed that this technology was doomed in its cradle as many overlooked its potential, while the inventors that produced the machines languished knowing something was brewing beneath the surface.

This is not to say that the people who contributed did not receive credit for some of the foundational research and thought processes that were fundamental to this industry. In 1995, Hideo Kodama was chosen to receive the Rank Prize, a privately funded British award for inventions, and was credited with creating the first of the key technologies for unlocking the rapid prototyping industry (Tomioka and Okazaki 2014). He shared this award with Charles Hull, our next inventor to highlight.

A few years after Kodama on the other side of the world we have Charles Hull, or Chuck, as he often goes by. This man is considered the father of 3D printing and is often where you hear the story of 3D printing begin. In the 1980s, he was working for an ultraviolet lamp company that added a layer of hard plastic onto surfaces, such as tables and countertops. After gaining permission from his superiors, Hull began to tinker after hours with a way to use the UV light to create tangible 3D objects from a Computer Aided Design (CAD) software, primarily utilizing the materials and science familiar to him through his daily work. He would experiment with photopolymers to lay the foundations of what would later cement him as the Father of 3D Printing. To which, there has been

contention to, and not just those hailing Hideo Kodama or the French as originators of the concept.

The material that Hull decided to use is called a Photopolymer. These materials are a type of plastic which harden and soften under different intensities of UV light. After a few design iterations, Hull created a finalized machine that manipulated minuscule plastic layers of photopolymer and each of these small layers combined to form the entire object. A simple cup, only a few inches tall, was the first item to be fabricated and represented a fundamentally different approach to our general notion of production (Davis 2014).

Through those long nights of toil, he invented the Stereolithographic (SL) process and filed for a patent in 1984, receiving it in 1986. He actually filed the patent 3 weeks after the French team and even further behind Kodama, but due to technical requirements and timing Charles Hull became the first person to patent and create a usable 3D printing method. What also lends to this standing as an industry founder is the creation of the Standard Tessellation Language (STL) file, which are still widely used today.

In the early 1990s, the Stereolithographic Apparatus, or SLA-1 machine, was created by 3D Systems with Charles Hull as one of the founders. Although with some error, this machine showed that complex parts could be built overnight or within a few hours using this method.

Primarily driven by tremendous cost, these cumbersome contraptions were more useful for transportation and other larger commercial industries. It was said that Charles Hull was obsessed with helping Detroit regain its competitive advantage as an influx of higher quality Japanese imports convoluted the market and moved manufacturing jobs away (Davis 2014).

Charles Hull was anticipatory of the gestation period that this type of technology would require while reaching full market awareness and publicity. In early interviews, he would project that it would take 20–30 years for the technology to find itself into more mainstream applications; however, it is with a combination of surprise and excitement that he now sees how this technology has grown in its capabilities (Davis 2014). His astute judgments, from projecting the amount of time the technology would require to become well-known to his imaginative nature that enabled him to contrive his invention, had helped to cement him as the father of this industry.

There were some, just like for Hideo Kodama, who felt that Charles Hull has been given too much credit for the creation of this industry while inadvertently leaving others in the dark; however, it takes a combination of belief in your product or process, dedication to create a company, and a little luck in the right market opportunity to make as large and noticeable of an impact as he has. As the saying goes: "to the victor go the spoils" – this is no less for Charles Hull. There are more people involved in the beginning of this industry than just he. So, we are going to wind back the hand of time a bit to capture our next inventor in the right light.

The 1970s was a time of expansion and exploration for many. For William (Bill) Masters, this was especially true. During this decade, he is said to have first speculated his form of 3D printing technology. From the South Caroline: A History of 3D Printing website, Bill Masters reflects on a kayaking trip he took where he recalls the moment when inspiration struck him:

> It was on a river trip. Back when I had the whole nine yards, the Volkswagen Van [and] the long hair, so when you're on the side of the river… and you're all laying there and looking up there at the sky at all those little dots up there – they call them stars. Why can't you make things in outer space? That's how it started; it started by looking at a star. (The Father of 3D Printing n.d.)

While he may have conceived his device early on, there were sets of personal circumstances that inhibited him from pursuing his musings of this concept until a few years down the road. Coincidently enough, when he did, he found it was around the same time that Charles Hull was also submitting his patent materials. That year was 1984, July 7th of 1984 to be exact. The date is special for William Masters as it was the date for which he filed the patent for his Ballistic Particle Manufacturing technology – patent #4665492 (USPTO Patent Full Text and Image Database n.d.-a). Most particularly, it is also a full

month ahead of Charles Hull's patent #4575330, which was filed on August 8, 1984 (USPTO Patent Full Text and Image Database n.d.-b). Charles Hull's patent application was accepted and published before the patent that Masters had submitted. To be realistic, it takes much more than a patent filing date and speculation of a concept to receive the credit of founding an entire industry.

Albeit, Masters contends that the birthplace of 3D printing is in North Carolina and also attributes the fact that Hull created a company along his patent almost immediately as a reason for his success. This is in contrast to Masters, who was not actively participatory until 1988 when he created Perception Systems, which later became Ballistic Particle Manufacturing (BPM) Technology. It was not until 1991 that his company, then newly titled as BPM Technology, obtained funding from Palmetto Seed Capital to create the machine based on his patent (The Father of 3D Printing n.d.). This was years after Charles Hull and other inventors had already forged a path ahead of him by creating different machines, processes, and were already selling machines based on their concepts.

In addition, it is distinct to note that even if the technology that Masters had created was to be as widely adopted as Hull's then there is doubt that it would have fared as well because it only creates structurally weak, hollow models. While Bill Masters may not have revolutionized 3D printing industry as a whole, he still filed a respectable amount of patents for technologies outside of 3D printing and also within this industry. Some of these patents include extruding fluent materials, 3D printing using pin arrays, and for the use of fluent material droplets (The Father of 3D Printing n.d.).

Selective Laser Sintering and Fused Deposition Modeling

As previously mentioned, there were many machines that also proliferated during this time as we come crashing into our next process. During the 1980s, there seems to have been an itch in many inventors' mind for machinery such as this, as our next innovator Carl Deckard comes into our crosshairs. Although many of these individuals were in completely different areas of the country, each seemed to be enraptured by automating the creation process behind three dimensional objects from the computer; however, just like their unique locations, each approached the concept in very different ways.

To say that Carl Deckard was young when he began his pursuit of this technology is an understatement. A freshman in Mechanical Engineering at the University of Texas in Austin, he spent his nights working in a metal shop that relied on the new, at the time, technology of Computer Aided Design (CAD) and began to daydream. He chose his major of Mechanical Engineering because he found that it was: "The closest thing to majoring in inventing" (Selective Laser Sintering and Birth of an Industry 2012).

Deckard was working for a facility in 1981 called TRW Mission, which crafted parts using CAD software; however, many parts were created from castings, or the castings themselves came from handcrafted casting patterns and he began to see that there was a potentially large market for creating casting patterns out of CAD Models. He envisioned lasers tracing themselves over fine layers of dust to bind together materials. By the time his senior year rolled around the only thing he needed to make his musings a reality were the parts to do so. An Associate Professor by the name of Dr. Joseph Beaman took the young student under his wing, then described as young and hungry, and the two began a trek to create this new form of machinery manufacturing.

Deckard began his transition into graduate school and, as luck would have it, the Mechanical Engineering Department was also moving to a new building, meaning that the budget had room for some equipment purchases. Beaman and Deckard took advantage of the opportunity and together they submitted a budget for the $30,000 worth of materials required to bring the idea to life. They affectionately dubbed the early stages of the Selective Laser Slithering (SLS) machine "Betsy," as it developed through the mid- to late-1980s. Although at first it was slightly crude method of production, as Deckard refilled a small box with powder by hand and ran the

computer which powered the scanner on top of the table. The first parts that were created were simply hunks of plastic to demonstrate that the concept could actually work. As he labored, though, more precise parts began to be produced by regulating the laser with the computer by writing code; upon evaluation, it was found that the parts produced were beginning to be of usable quality. At that point, Deckard called upon Beaman to write it up for his Master's degree because he had just created an entirely new and viable machine. He was none the wiser that this would lay the foundation of some incredible processes in 3D printing technologies in the decades to follow.

Deckard stayed at the University of Texas to continue refining the idea, receiving a grant from the National Science Foundation. They enclosed the rudimentary aspects of the machine into an electrical box, added a counter-rotating roller to level the powder between layers of the laser sintering (which was being done by hand before), and after the method had been fully polished the parts began to coming off the machine at a higher quality. It was then that the machine started to show the makings of something more versatile than just creating casting patterns.

Paul Forderhase, another graduate student, joined the efforts as the concept matured from being an undergraduate dream to a graduate project and was now gaining enough momentum to seek becoming a commercial company. An Austin business owner by the name of Harold Blair paired with an Assistant Dean of Engineering and occasional adjunct professor by the name of Dr. Paul F. McClure. They had become interested in the technology and the company was named Nova Automation – after Blair's existing company called Nova Graphics International Corporation. Deckard estimated that they would need $75,000 in startup capital to get off the ground, which was doubled by Beaman, and then doubled again by those overseeing the project bringing their estimated startup cost to $300,000 – this was just to keep the interests of Blair and McClure (Selective Laser Sintering and Birth of an Industry 2012).

After a few hit and miss opportunities for funding with several companies through the 1980's and 1990's, one of which actually involved William Masters from the then Perception Systems, Nova Automation received funding from the Goodrich Corporation. With this funding they were able to keep Blair on board and they renamed themselves the DTM Corporation. It was a reference to the term Desk Top Manufacturing or some have said it is a reference to the words "Deckard, Texas, and McClure".

Unfortunately, even after their hard efforts the technology was seen as a reflection of an industry still in its infancy and did not fare well. The majority shares were sold to a group of private investors, who then turned around and sold the company and concepts to 3D Systems, which allowed them to acquire key patent rights to the SLS technology. For 3D Systems to now hold the rights to SLS and SL technologies has played to the company's power position as the "world's leading provider of additive manufacturing technologies."

When it comes to market dominance, Stratasys is one of the few companies to challenge 3D Systems when it comes to their lion's share of control. Scott Crump, founder of Stratasys, patented the Fused Deposition Modelling (FDM) technology in 1989 (Perez 2013). Not only is it the most familiar form of 3D printing for the public, it was actually a pursuit with adorable roots. In 1988, Crump decided that it would be a wonderful idea for him to make a toy frog for his young daughter using a glue gun loaded with a mixture of polyethylene and candle wax (Perez 2013). With the support of his wife, and several burnt plastic pans later, he soon became obsessed and took his project to the garage – where he devoted many long weekends to it. He invested into digital-plotting equipment (which cost about $10 K) to help automate the process and the first prototypes of the toy began to be churned out.

His wife prodded and pushed for him to either turn this affixation of his into a viable company or give it up because he had already spent tens of thousands of dollars to produce one supposed toy for his daughter (Perez 2013). By that time though, it had evolved into a larger project, a mission, a higher calling than simply creating a plastic trinket toy for his beloved. He saw the

potential of a machine like this as he clacked away many nights in his garage.

The first of the Stratasys kits were $130,000 and not viable for the regular consumer market, nor really even for small businesses (Perez 2013). Much like 3D Systems, their efforts were revised and they began to focus selling his machines to larger corporations that had the funds necessary to fuel his refrigerator-sized machines. They liquidated all of their family assets and poured everything into their company to get it to that point. However, to even fulfill the first orders they would require the support of venture capitalist – they found a company willing to invest in the concept called Battery Ventures. The company took a 35% stake in the company for $1.2 million (Perez 2013).

Since then, Stratasys has evolved to be one of the largest companies in the world for 3D Printing – often battling for glory alongside 3D Systems. Scott Crump is a formal Mechanical Engineer who heads this company and he is credited with Charles Hull et al. as one of the founders of the 3D printing industry. In 2013, Stratasys strategically bought out MakerBot – who has become a household name for the home desktop 3D printer.

EOS and the Evolution of Selective Laser Sintering

This machinery was a global phenomenon during its development, Hans Langer formed Electro Optical Systems (EOS) GmbH in Germany around the same time that patent applications for the first forms of this technology began flying around the United States in 1989. Still true to this day, EOS machines are recognized for their superior quality of output that utilizes the Laser Sintering (LS) process. Their first 'Stereos' machines were sold in the 1990's, making them the first European provider of high-end rapid prototyping systems.

As to what motivated Langer to strike it off into unknown territory such as this was actually the cloudy doubt cast by others which enabled him to see the light of potential. At the time he was working for a company called General Scanning, which evaluated additive manufacturing technologies at a project level, and they decided not to invest into developing the technology. Langer remained unconvinced of their decision. He firmly believed that the technology would be the future. He formed his own company in 1989 and set off to create a new and viable industry. By the amount of sheer success that he has encountered, time has shown that his judgment was sound.

If the previously mentioned words "Laser Sintering" were familiar, you were keen. The technology was originally created in the United States and had an interesting pathway to this German-based company. When Carl Deckard's company failed and 3D Systems gained the U.S patents on the SLS technology, they also entered an agreement with EOS where 3D Systems would purchase a product line from EOS, which was directed at SL technologies, while EOS would be able to take over global patent rights on the SLS technology. This included other interesting developments of Laser Sintering, such as applications of metal manufacturing.

Under the same umbrella that Carl Deckard worked under, Suman Das also developed applications for SLS technology at the university, except he used metal powders for his Master's and Ph.D studies. It may come as a surprise to no one that he was also under the supervision of Joe Beaman. If that name sounds familiar it is because he was the same man who aided Carl Deckard in his pioneering in the original Laser Sintering concept. Under the Defense Advanced Research Project Agency (DARPA), Office of Naval Research (ONR), and Air Force Research Laboratory (AFRL) sponsorship, Suman designed and built two additive manufacturing machines and aided in co-inventing two laser-based additive manufacturing processes in metal for specific use in high performance aerospace components (Selective Laser Sintering, Birth of an Industry).Thus, enabling the ideas from a Texan student to reach the global market through a German company.

The development in technology in Germany can be dizzying due to massive amount of cross

collaboration between key companies. An offshoot process to SLS called Selective Laser Melting was initially developed in 1995 at the Fraunhofer Institute for Laser Technology (ILT), two Doctors by the names of Dr. Dieter Schwarze and Dr. Matthias Fockele, who then formed F&S Sterelithographietechnik GmbH.

Around the same time, a company by the name of TRUMPF Group began to work with their own brand of this technology based on the ILT research. What also makes them a powerful contender in the 3D printing market today is their extensive history of precision laser systems, and the fact that they also happen to hold exclusive rights to ILT DMLS patent portfolio. DMLS is Direct Metal Laser Sintering, which combines SLS and SLM properties. This technology was created in 2002 with a collaborative agreement between EOS and TRUMPF where they decided to share key technology with the goal of enabling more growth between the methods, based partially on the research that TRUMPF Group leveraged from the ILT.

Always eyeing advancement, in 2008 EOS/TRUMPF announced an agreement with a company called MCP (who was itself partnered with F&S Sterelithographietechnik) for patent licenses that expanded EOS and TRUMPF laser-sintering patents, specifically the machinery that enabled titanium and aluminum powder manipulation; however, the patents did not extend to North American and when MCP attempted to sell a machine, the Realizer, in the USA through 3D Systems they landed in some hot water with EOS. They had technically performed patent infringement and EOS pursued a lawsuit against them. After settling the lawsuit for an untold amount of money, MCP (now MTT) went through some hand changing and consolidation to reform itself as a private company under SLM Solutions GmbH, who now sells their own brand of SLM machinery.

Conclusion

3D printing is bounding forward quickly, crafting vehicles, organs, and even homes in its wake. The decades will blur by and the innovation will exceed our expectations, as they did for Charles Hull. 3D printing is set to carve an interesting niche for itself, uniquely performing where traditional methods fail, while also turning the table of development. While it may truly never replace mass manufacturing, the changes it makes in our supply chain and the way we view manufacturing as a whole can cause us to change as creators and consumers. This is where the power of 3D printing lays, in its ability to enable creativity and innovation in places we thought it was stagnate, to bring increased individuality to the products we consume, and rethink our manufacturing process now that we are brought more intimately to it.

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3D Puzzle Games in Extended Reality Environments

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Synonyms

Augmented reality; Extended reality; Mixed reality; Spatial interactions; Virtual environments; Virtual reality

Definitions

Augmented reality (AR): It can be defined as a medium where the virtual models are augmented onto a real-time objects, or a virtual information overlayed on top of a real-world objects or space.

Virtual reality (VR): It can be stated as a medium which provides three-dimensional immersive environments which allow the user to interact with the digitally created objects.

Mixed reality (MR): As the name suggests, it is the medium where virtual, i.e., digital objects and real-time physical objects coexist and interact with each other.

Extended reality (XR): It is an umbrella term which encompasses technologies like VR, AR, MR, etc. and their combined experiences.

Introduction

Games bring the attention and indulges a person in an activity irrespective of the age. Games have been around humans since the dawn of history and they are inextricably intertwined with the human evolution. In recent times, as the digital technologies evolved, video games became more popular among all age groups of people. In that, puzzle video games were primarily designed to keep the player/s engaged by testing the ingenuity or knowledge. The games were designed with increasing levels of complexities to cater to the tendency of the players to move to higher complexities and challenges. Thus, once the player solves or reaches the end of a level, it gave the sense of satisfaction which in turn enhanced the engagement of the player with the games. Dissected or jigsaw puzzles are spatial rearrangement games which involves visuospatial thinking and problem-solving. John Spilsbury, a London-based cartographer, is considered as the creator of jigsaw puzzles (Williams 2004). In 1760s, he first created such a puzzle by pasting the map of different kingdoms in Europe on a wooden plank and dissected it into the maps of individual kingdoms. Such maps were marketed as tools for geography education for children. These puzzles are challenging and also enhances the motor ability and constructional praxis in children. These games have come off the age through different transformation. The early transformations include "three-dimensional jigsaw puzzles" which was patented by Hammer Willie in 1961. Host of interesting geometric puzzle designs have been explored by Stewart Coffin (2006). Many researchers have explored algorithmic analysis and synthesis of such puzzles (Song et al. 2012). Though the computers can create interesting puzzles in the digital environment, they are unable to actively engage with the players, unless the interaction medium supports this complex perceptual task. Toward this, a host of digital interactive technologies have been developed to make seamless interaction with the virtual digital world. The advent of technologies like virtual reality (VR), augmented reality (AR), and mixed reality (MR) have shown a great promise to facilitate such puzzle games in

the modern era. Such interactive gaming modalities have the potential to solve the present-day challenges. This article presents the role and possibilities of 3D puzzle games in the context of spatial, immersive interactive technologies like VR, AR, MR, etc. which are collectively known as extended reality (XR) technologies.

VR in Gaming with Puzzles

Virtual reality (VR) immerses the human's mind into another realm, thus by deceiving the human senses, which aligns the brain with alternative reality. In VR, stereoscopic displays, software platform, motion-tracking hardware, etc. are used to generate a virtual environment. In VR systems, the user is unaware of the physical (real) surrounding. This also implies that there is a higher degree of engagement with the virtual environment and enhanced cognitive involvement. Perception of spatial arrangement is essential for virtual games with puzzle metaphor. Such games developed for applications like spatial perception (Rasheed et al. 2015) and anatomy education (Pohlandt et al. 2019). To facilitate greater immersion into the virtual environment, the mapping between the human sensorial inputs corresponding with the spatial transformation of virtual objects in the scene should be consistent. Thus, it is the responsibility of the VR content developers to achieve realistic immersion into the virtual environment.

AR/MR in Gaming Puzzles

AR technology can help in transforming a physical space through spatial interaction with the virtual data overlapped to create an engaging environment. In the context of assembling a 3D puzzle, user gets continuous feedback based on their actions while assembling the puzzle pieces. One such example is demonstrated in using projection-based technique (Kitagawa and Yamamoto 2011), in which the user is guided by projected image on the tabletop. These technologies facilitate physical puzzle interactions with digital overlay of information to support the game play. Augmented reality system integrates computer-generated information with the help of sensors to create 3D virtual models, which has to be calculated along with the user's position and orientation. These technologies are also ubiquitous because it can be deployed on the smartphones, and utilize the functionalities of the AR applications (Roberto et al. 2019). This technology has potential to greatly transform interactive experiences of 3D puzzle games.

Interactions in XR Media for Puzzles

Physical puzzle games make the users to think logically by interacting with the pieces to solve the puzzle. A game's physical aspect consists of interactions such as touch and feel, and emphasizes on physical skills of a player in solving it with emotional cues. Computer games have limitation of physical interactions to the players' use of interface hardware to play the game (Nilsen et al. 2004). Puzzles require users to randomly arrange the elements, thus entailing the cognitive activities such as exploring all the possibilities and improving the strategy development. 3D puzzles help users to think differently than the traditional 2D puzzle pieces. As 3D puzzle would have an extra dimension to it and becomes more challenging to solve it than a 2D puzzle set. Using 3D puzzles as a metaphor can greatly enhance the interactions in XR medium. The major potential of XR is in altering how we perceive the virtual world with the help of computer-mediated user experience. This disruptive behavior in leading to paradigm shift in the applications developed in various domains like health care, education, entertainment, military applications, etc. Thus, such user interfaces must have a richer visual content and seamless interaction between real and virtual worlds with the help of intuitive sensing, tracking, and feedback technologies. One of the important factors in facilitating interactions through XR media is to have reliable spatial interactions. The 3D puzzle metaphor is extremely

useful to achieve these seamless interactions as described in the framework presented in the following section.

Framework for Interactions in XR

Based on the prior experience of developing XR applications, a framework is derived which would be useful for developing applications for any routine task which can be made more engaging and convenient for the user with the help of XR technologies.

Assembling the components of a puzzle consists of various steps and should be done in a systematic sequence. Hence, it involves an architecture integrating software and hardware. The architecture of the system is shown in Fig. 1. Here, when the user gazes at a three-dimensional object through a hardware such as Microsoft HoloLens® which has camera embedded to it, the spatial information of the object is captured by the camera through the markers and this information is provided to the software to process and identify the object. Once the objects are detected, the corresponding animations will be triggered and information explaining the process of interactions of physical objects will be provided. Further actions are triggered depending on the user feedback, and this process will continue until the task is completed successfully or any other conditions of termination of the interaction. Robust implementation of this framework for creating a better user experience depends on the components of the framework described below.

Object Recognition

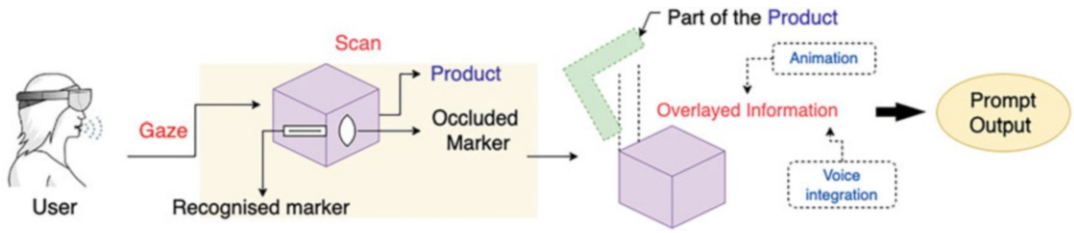
To augment any physical task with the support of XR technologies, it is required to capture the physical scenario into digital format. Thus, object recognition technologies will help in capturing the physical scenario. There are multiple aspects of identifying the object or object recognition such as the perspective views and the angles related to the object. Image-based object recognition technologies are useful for 2D planar scenario. In 3D, capturing and identification of objects is complex. Though there are many technologies like 3D scanning (Tucker et al. 2014), depth cameras (Langmann 2014) etc. to reconstruct a 3D space, but still the challenge is to solve it in real time.

Movement or Orientation

When a successful object recognition is done, the next aspect is to facilitate movement or the orientation of a particular 3D object. When the dynamic object moves in the space, one can understand the transformation components such as translation, rotation, scale, etc. covering all the three axes.

Interaction Between the Physical and the Virtual Objects

Interaction can be defined as communication and reciprocal actions between two entities to reach a common functional goal. The interaction between a physical object and the virtual object can be defined as both representations are interdependent. The interaction of bimanual motor skills enables the user to perform interactions that can be through narrative essentials such as hand gestures, voice, or gaze.



3D Puzzle Games in Extended Reality Environments, Fig. 1 *Framework* of interaction in XR system with voice interaction

Voice Interaction

Voice is an important aspect as it is a part of interaction by which one can quickly get responses from the system. The role of virtual voice assistant can be seen as an embodiment. As mentioned earlier about the continuous feedback, the role of voice is essential when the interactions are bimanual and also when the user has to perform multiple interactions.

Applications

Virtual reality can provide seamless immersive experience in interactive 3D medium. The essence of virtual gaming can be put into various fields such as education and training, which can be very engaging and enhance users' expertise (Rasheed et al. 2015).

Mixed reality has various entities such as specialized equipment and efficient software, and with the recent advancements in technology many devices have emerged as potential interfaces, such as Microsoft HoloLens®. Hence this technology has become ubiquitous and can be used in various sectors such as education (Rasheed et al. 2015), training and simulations (Mujber 2004), product repair and maintenance (Paravati 2017), entertainment, health, and military applications. Majority of MR's potential can be used in product assembly and the execution of industrial tasks. MR is also used in construction industry as a tool to BIM (building information modelling), to understand the three-dimensional models (DaValle and Azhar 2020).

3D puzzles are one of the best examples of an assembly. The user has to carefully place the pieces of the puzzle in such a way that it makes it as a single unit. Often, users fail to assemble the parts of a device or a piece of furniture. Thus, it results in failure of the product and have to end up losing money for repair. Solving 3D puzzles are highly engaging task as it plays with the third dimension as compared to a traditional 2D jigsaw puzzle. Such interfaces are extremely relevant to the applications like manual assembly of machine components. Puzzles can be interesting metaphors for VR system designs. Especially in VR games, puzzles help in developing mechanics of the games (Nyyssönen and Smed 2021). Thus, the use of technology such as XR can help in guiding the novice users to a precise point/dimension by detecting points on the physical objects. It helps in building a virtual space to visualize content and solve problems such as tedious job of assembly into an interesting one.

Cross-References

- ▶ Augmented Learning Experience for School Education
- ▶ Augmented Reality for Maintenance

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3D Reconstruction

▶ Deep Learning Algorithms for 3D Reconstruction

3D Rendering

▶ Panda3D

3D Room Layout System Using IEC (Interactive Evaluational Computation)

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Synonyms

Interactive design; Interactive genetic algorithm; Interactive room layout

Definition

IEC is the interactive optimization system incorporating human tasks. 3D room layout system using IEC is the application of IEC, and it evolves layout according to the user preferences.

Introduction

Designers usually build renderings to create a new layout, and they reorganize it to fit a customer need. Furthermore, customers can understand shapes intuitively if they provide the 3D room layout. Numerical optimization approaches that optimize parameters constructing the 3D room layout can automate these works. However, it is difficult to create a model equation that emulates human thoughts because it is a subjective personal preference. Therefore, optimization systems incorporate the human tasks that evaluate the fitness of solutions manually. These systems usually use interactive evolutionary computation (IEC). This approach is similar to the process of improvement in animal and crop varieties. Some evolutionary computing algorithms implement IEC. The most famous algorithm is interactive genetic algorithm (IGA), and some studies use parallel distributed interactive genetic algorithm (PDIGA), interactive differential evolution (IDE), interactive particle swarm optimization, and interactive genetic programming (Takagi et al. 1998, 2009). This entry focuses on IEC and interactive 3D room layout, and it especially treats the system that uses IGA. The remainder of this entry organizes as follows. Section "Algorithms for IEC" gives the algorithms for IEC and examples of some applications. Section "Layout Generation" shows the studies that generate 3D layout interactively. Section "Quantitative Evaluation Techniques and Problems of the IEC-Based Systems" describes quantitative evaluation techniques and problems of the IEC-based system. Finally, section "Summary" summarizes this paper.

Algorithms for IEC

Richard Dawkins famed for *The Selfish Gene* began the study of IEC (Dawkins 1986). Afterward, various fields such as arts, engineering, education, and entertainments incorporate IEC (Bentley 1999). Takagi organized the applications of IEC between 1986 and 2000 (Takagi 2001). Table 1 lists the major application. The following are specific advantages of IEC:

1. Personalize applications based on user preferences.
2. Incorporate knowledge and heuristics of users to the system.
3. Aid creativity of users.
4. Provide user-friendly applications that need not special skills and knowledge.
5. Analyze user preferences by using optimized solution.

Interactive Genetic Algorithm

Genetic algorithm (GA) is a heuristic search algorithm, and it bases on the Darwinian theory of evolution. It finds the optimum solution by generating individuals that can be the optimum solution. Each individual that is in the population develops through the fitness function that determines the ability to solve problems, and crossover and mutation elevate individuals. IGA replaces the fitness function with the user evaluation to incorporate user preference and knowledge.

Table 2 shows the pseudo-code for typical IGA. The user rates the evolved individuals, and IGA generates new individuals according to the user evaluations. The following are specific procedures:

1. Initialization: This process generates the initial individuals. Typical IGA creates genes configuring an individual randomly.
2. Evaluation: This is the human task. The user rates individuals based on his/her subjective preference. IGA uses these evaluations as the fitness values to evolve the current individuals.
3. Selection: This process selects some highly rated individuals as parents to create a new generation. The following are specific selection methods:
   - Roulette selection: This method selects parent individuals according to a rate that is proportional to the fitness values. Typical roulette selection uses the selection boxes that have room according to the fitness values and random numbers, and it selects the individuals by checking the random numbers that are in the selection boxes. The following is the probability selecting ith individual, where n is the number of individuals and f is a fitness value.

$$p_i = \frac{f_i}{\sum_{k=1}^{n} f_k}$$

   - Tournament selection: This method selects parent individuals by using knockout competition.
   - Elitist selection: Roulette selection and tournament selection have the potential to lose the best individual because they are probabilistic methods. This method bequeaths the elite individual to the next generation, and it does not apply crossover and mutation to the elite individual.

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 1 Examples of IEC applications

Creativity	Comfortable design	Personalize
Biomorph	Lighting	Hearing aid
Face image	Web page	Vision aid
Screen saver	Vehicle	Image retrieval
2D/3D CG	Building	Knowledge transmission
Modeling	Interior layout	Knowledge acquisition
Animation	Clothing	Robot arm control
Music	Schedule	Educational aid
Voice	Game	Advertising
Artificial life	Story composition	Seasoning adjustment

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 2 Pseudo-code for typical IGA

```
IGA ( )
  generation = 0;
  create initial group of individuals;
  REPEAT
    fitness = USER (current group of individuals);
    IF user is satisfied THEN RETURN the best individual;
    i = 0;
    REPEAT
      select two individuals based on fitness;
      perform pcrossover;
      perform pmutation;
      insert two offspring into new group of individuals;
      i = i + 2;
    UNTIL i > predefined number of individuals;
    generation = generation + 1;
  UNTIL generation > predefined number of generations;
STOP
```

4. Crossover: This process transposes gene sequences of two individuals. The following are specific crossover methods:
   - Single-point crossover: This method splits a gene sequence into two halves. Children inherit the parent gene sequences half-and-half.
   - Multi-point crossover: This method has some split-off points. Children inherit the parent gene sequences alternately.
   - Uniform crossover: Children inherit the parent gene sequences according to a randomly generated mask.
5. Mutation: This is a way to change a part of gene in an individual randomly with a fixed probability. It is a useful way to prevent the initial convergence. Typical mutation uses the reciprocal of a gene length as the mutation rate.
   - If a specific individual generated in an early stage has an extremely high fitness value, IGA may select it as an optimal solution. This is the initial convergence, and it is a problem in IGA. It converges exploration in the early stage, and solutions lose the diversity.

IGA iterates these operations (2–5) until the user obtains a satisfied result or the number of iterations exceeds the predefined constant. The performance of IGA depends on the operators. There are many methods other than listed above (Koza 1992) (Fig. 1).

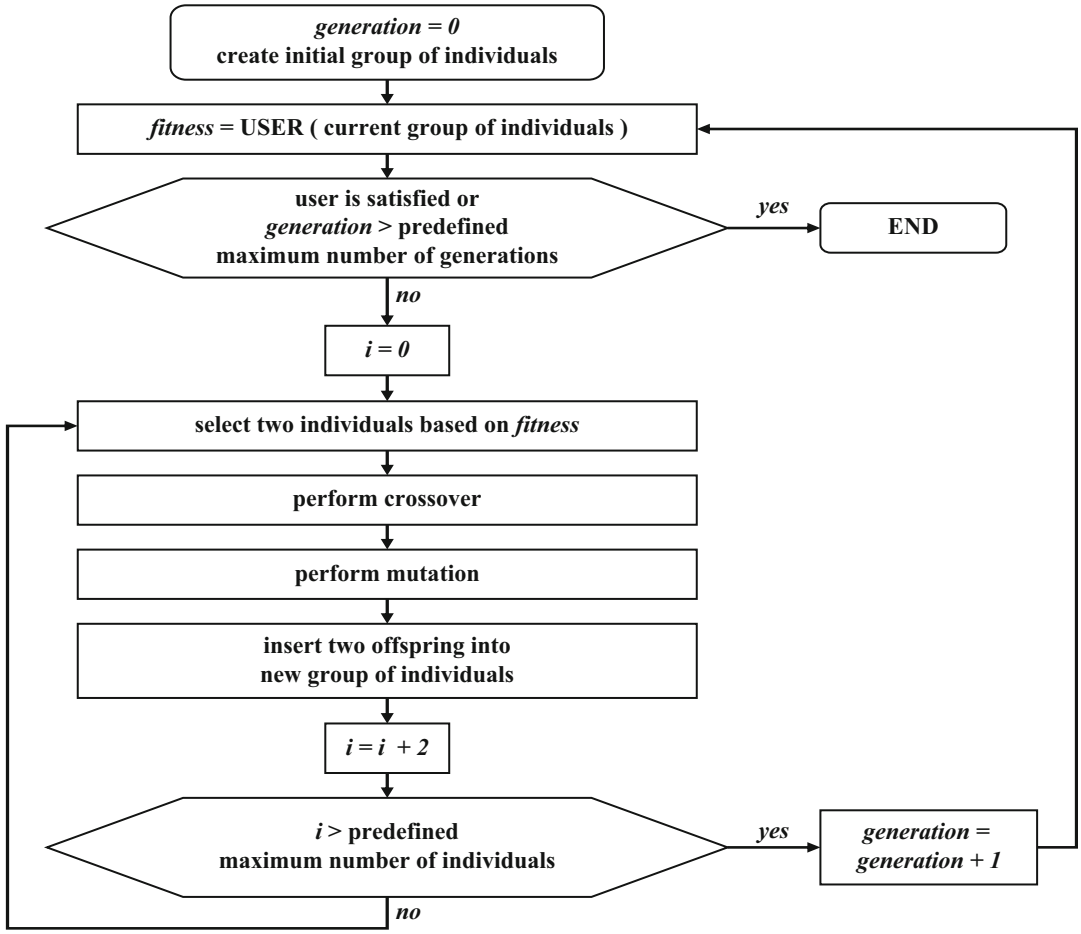
Gene Expressions IGA has many types of gene expressions as with GA (Back 1996). An individual has the genotype and phenotype. GA operators operate genotype, and the user evaluates phenotype. The following are typical genotype expressions:

(a) Binary code: This method expresses genes as binary codes.
(b) Gray code: This method expresses genes as the codes that maintain the difference of adjacent nodes at 1 bit, and it facilitates the local search. The following are the conversion equations of binary codes and gray codes, where k is the bit location and n is the most significant bit:

$$g_k = \begin{cases} b_n & (k = n) \\ b_{k+1} \oplus b_k & (otherwise) \end{cases}$$

$$b_k = \sum_{i=k}^{n} g_i (mod\ 2)$$

(c) String: This method expresses genes as strings. Mutation operator changes a gene element within the predefined character set.
(d) Real number: Real-coded GA uses real numbers directly. The IGA that emphasizes continuous values uses this coding. It can generate children around the parents. However, real-coded GA needs the special crossover operators such as unimodal normal distribution crossover (UNDX). It generates children according to the normal distribution obtained from three parents (Ono et al. 2000) (Table 3).



3D Room Layout System Using IEC (Interactive Evaluational Computation), Fig. 1 The flowchart of typical IGA

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 3 Typical genotype expressions

Phenotype	Binary code	Gray code	String	Real number
1.0	000	000	"1.0"	1.0
1.5	001	001	"1.5"	1.5
2.0	010	011	"2.0"	2.0
2.5	011	010	"2.5"	2.5
3.0	100	110	"3.0"	3.0

Parallel Distributed Interactive Genetic Algorithm

Miki et al. proposed parallel distributed interactive genetic algorithm (PDIGA) (Miki et al. 2003, 2006). Table 4 shows the pseudo-code for typical PDIGA. This algorithm extends IGA to parallel distributed model, optimizing solutions according to the multiuser preferences. It can generate the new solutions combined with other user evaluations, used in consensus building system. PDIGA inherits the performance of PDGA that can reduce the computation time and avoid the initial convergence of GA. PDGA connects each computer and

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 4 Pseudo-code for typical PDIGA

```
PDIGA ( )
    generation = 0;
    create initial group of individuals;
    REPEAT
        receive an elite individual;
        insert the elite individual into current group of individuals;
        fitness = USER (current group of individuals);
        send a new elite individual;
        IF user is satisfied THEN RETURN the best individual;
        i = 0;
        REPEAT
            select two individuals based on fitness;
            perform crossover;
            perform mutation;
            insert two offspring into new group of individuals;
            i = i + 2;
        UNTIL i > predefined number of individuals;
        generation = generation + 1;
    UNTIL generation > predefined number of generations;
STOP
```

runs IGA on those computers. PDIGA uses the migration that sends and receives the elite individual each user selected, incorporating other individuals.

They also proposed global asynchronous distributed interactive genetic algorithm (GADIGA). It compiles the elite individuals in a database so that each computer can migrate them without synchronism. Each computer gets the elite individual from the database, incorporating it in own group of individuals.

Interactive Differential Evolution

Storn et al. proposed differential evolution (DE) that is a population-based descent method for numerical optimization (Storn et al. 1997). The following are specific advantages:

1. Completeness: It searches comprehensive optimized solution.
2. Efficiency: It needs a small number of times of evaluation.

Takagi et al. explained advantages to use DE for IEC as follows (Takagi et al. 2009):

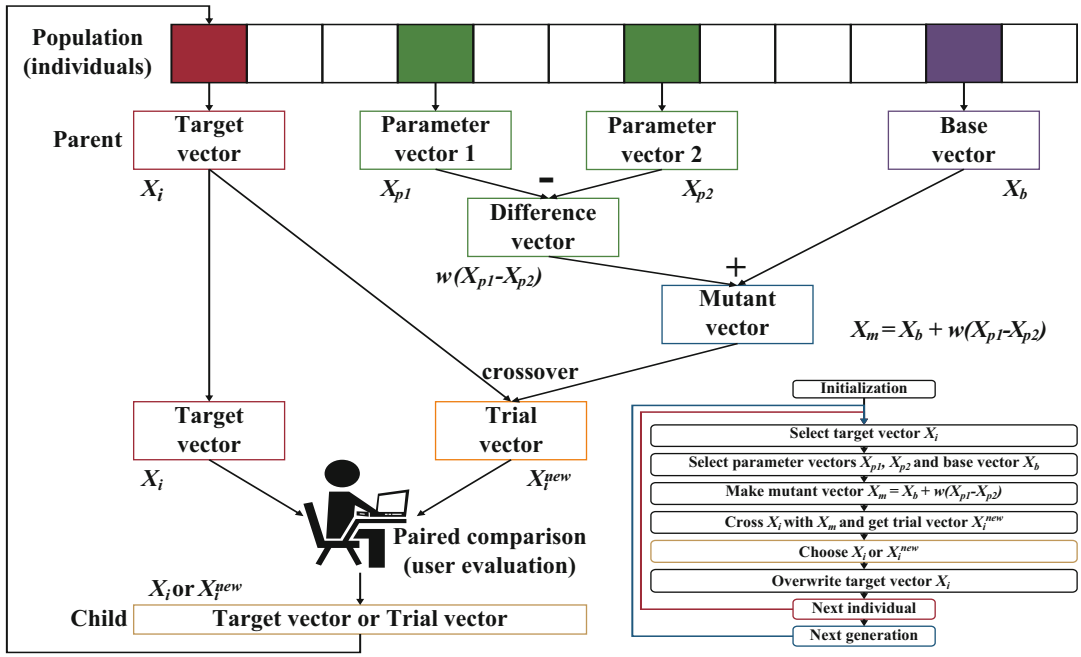
1. The user can use the paired comparison evaluation.
2. It has a good convergence characteristic in a small population.

DE has some formats, and it expresses as DE/base/num/cross. The following are specific formats:

(i) Base: The selection method of a base vector.
- Rand: Select a vector from a parent group of individuals randomly.
- Best: Select the best vector from a parent group of individuals. DE/best has better convergence performance than DE/rand. However, it needs parallel comparison of all individuals to select the best vector.
- Gravity: Select a centrobaric vector from a parent group of individuals. DE/gravity has almost the same convergence performance as DE/best, and it needs not parallel comparison of all individuals (Funaki et al. 2011). However, the convergence performance will deteriorate if the centrobaric vector is quite different from the global optimum solution.
- Moving: This selection method works with another selection method. It makes a moving vector that accumulates the difference between a target vector and trial vector, and it adds the moving vector to the base vector to accelerate the convergence performance.

(ii) Num: The number of difference vectors.

(iii) Cross: The crossover method of a target vector and trial vector.
- Bin: Use the binomial crossover that performs a crossover with a fixed probability.



3D Room Layout System Using IEC (Interactive Evaluational Computation), Fig. 2 The conceptual diagram and flowchart of IDE

- Exp: Use the exponential crossover that performs a crossover with the probability decreases in an exponential manner.

The user evaluates individuals in interactive differential evolution (IDE) as with IGA. Figure 2 illustrates the conceptual diagram and flowchart of IDE. The user selects the target vector or trial vector, and he/she repeats it until the number of evaluated target vectors exceeds the predefined number of individuals to obtain a next generation. IDE reduces the burden of user evaluation because it needs not parallel comparison of all individuals except for DE/best. However, the user needs to compare four individuals in the evaluation stage when used in combination with the moving vector. The user selects a vector from the target vector, trial vector, combination of target and moving vector, and combination of trial and moving vector in this case. In addition, Pei et al. reported that incorporating the opposition-based learning with IDE could improve the quality of group of individuals (Pei et al. 2013) (Table 5).

Examples of the IEC Applications

Many researchers elaborate IEC applications, improving performance and extending application ranges. This section introduces some applications developed in recent years.

Web Page Design Sorn et al. proposed the design system that generates a template for Web page interactively using IGA (Sorn et al. 2013). Although the work of creating and designing Web pages is increasing, they are time-consuming tasks. In addition, users have to learn the programming languages such as JavaScript and usages of authoring tools so that they can create the particular Web page. The proposed system evolves HTML and CSS based on the user preferences, and genes represent the layout expressing a location of navigation bar and styles such as font color and size. It displays ten Web pages as individuals in a generation, and the user gives ratings of one

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 5 Pseudo-code for typical IDE/rand/1/bin

```
IDE ( )
  w = predefined weighting coefficient;
  generation = 0;
  create initial group of individuals;
  REPEAT
    i = 0;
    REPEAT
      x_i = select a target vector from current group of individuals;
      x_p1, x_p2 = select parameter vectors from current group of individuals randomly;
      x_b = select a base vector from current group of individuals randomly;
      x_m = x_b + w * (x_p1 – x_p2);
      x_new = make a trial vector from x_i and x_m by using binomial crossover;
      x_i = USER (x_i, x_new);
      IF user is satisfied THEN RETURN x_i;
      i = i + 1;
    UNTIL i > predefined number of individuals;
    generation = generation + 1;
  UNTIL generation > predefined number of generations;
STOP
```

(good) to five (bad). Furthermore, the user can evaluate each section such as header and footer particularly so that the system reflects the specific user preferences.

Fashion Design Mok et al. proposed the design system that generates a fashion sketch interactively using IGA (Mok et al. 2012). The design aid is useful for increasing productivity. The proposed system has a sketch design model describing the characteristics of the design, a database storing sketch design models, and a multistage sketch design engine that builds the final design. Mok et al. demonstrated the system making the skirts design. Genes represent the silhouette, shape, type of waist and hem, and decoration such as dart, yoke, pleat, panel, gathers, slit, and ruffles. The system generates initial population based on the waist level and skirt length the user decides at the beginning, and it evolves the skirt design.

Refactoring Ghannem et al. proposed the design system that generates a sequence of refactoring interactively using IGA (Ghannem et al. 2013). Refactoring is a technique that restructures existing models such as class diagrams in a software development cycle, and it improves design quality while preserving its semantics. It is difficult to automate a complex refactoring and evaluate the quality and integrity of refactored models because it needs empirical rules. The proposed system incorporates feedback from users into the optimization processing, and it uses the first knowledge obtained from examples of refactoring and the second knowledge obtained from users. The system analyzes the similarities of examples and inserts the second knowledge interactively, and it displays applicable refactoring while optimizing a model. Genes represent the sequence of refactoring operations such as "pull-up method," "rename attribute," and "move attribute." The system applies these operations to compose models and gets the evaluation the user scored using the five-level scale.

3D Motion Akase et al. proposed the design system that generates a 3D motion of the

Avatar interactively using IGA (Akase et al. 2012). Movies and computer games use 3D motions to make the motion of 3D characters. Generally, designers generate 3D motions using motion capture systems. However, it is difficult to create various 3D motions. The proposed system creates a unique 3D motion by considering a physical limitation. It combines the inverse kinematics with IGA to reduce the variables required for motion optimization, reducing the burden of user evaluation effort. The system optimizes the trajectory of end effectors instead of the joint angles. Genes represent the traveling sequences in common with the gene expression of traveling salesman problem. As with the feature Sorn et al. introduced, the user can evaluate each body part such as the head, arms, and legs particularly so that the system reflects the specific user preferences.

Layout Generation

This section introduces the methodologies to create the interactive 3D layout generation system.

Automatic Layout Generation Based on the Constraints

In recent years, designers create city design and room layout in a virtual world. For example, "City Engine" can create cities including street layouts and buildings automatically. Parish and Muller proposed this system, and they use a procedural approach based on L-systems to model cities (Parish et al. 2001).

The layout work for 3D virtual rooms takes a long time because 3D objects have six degrees of freedom. In addition, 3D furniture objects have furniture-specific features. For instance, TV needs some space for its watchers to watch, and desk and chair need pairs generally. These features are associated with ergonomic design. Akazawa et al. proposed a system that generates 3D scene automatically based on contact constraints (Akazawa et al. 2005, 2006). The proposed system makes scenes by using a semantic database. The following are specific attributes of the semantic database:

1. Face: Indicate the surface number of bounding box wrapping the 3D furniture object.
2. Occupancy distance: Indicate the minimum distance not to touch other objects.
3. Parent: Indicate the parent objects.
4. Constraint: Indicate whether a face should touch a certain face of other object or not.
5. Inside component: Indicate the objects placed inside the object.
6. Connection width: Indicate the width number of objects to place them in the rectangular area.
7. Connection depth: Indicate the depth number of objects to place them in the rectangular area.
8. Connection face: Indicate which faces of the bounding box are connectable.
9. Raito: Indicate the ratio of the number of objects in a width direction to the number of objects in a depth direction.

Similarly, Lap-Fai et al. proposed automatic 3D layout systems based on ergonomics constraints (Lap-Fai et al. 2011). They defined ergonomics as follows:

1. Accessibility: Maintain the space for furniture to perform a basic furniture function.
   - For example, bookcases need extra space for books.
2. Visibility: Maintain the sight for human to look viewing surfaces.
   - For example, other objects should not block a television.
3. Pairwise relationship: Maintain the semantic compatibility between objects.
   - For example, place a desk and chair in pairs.

Their system executes the following processes to arrange many objects:

(a) Create relationships between one object and the other: System learns relationships from preliminarily ordered 3D layout.
(b) Optimize the layout: Minimize the number of inappropriate objects that violate the ergonomics constraint using simulated annealing.

Interactive Layout Generation Using the Language and the Real-World Information

Calderon et al. proposed the interactive furniture placement system using the constraint logic programming (Calderon et al. 2003). The user can obtain knowledge and skills of the room layout design by using the system. Similarly, Coyne et al. developed Words Eye that generates 3D scenes using the natural language (Coyne et al. 2001). Words Eye parses several sentences to extract the object information and tags the corresponding label, and it depicts a 3D scene from 2000 shape data and 3D texts.

Alternatively, several studies use a 3D scanner and an RGBD camera to make 3D scene data from the real-world scene information. For instance, Nan et al. and Kim et al. proposed a new method that makes 3D scenes using a 3D scanner (Kim et al. 2012; Nan et al. 2012). In addition, Shao et al. developed the system that searches similar 3D shapes from a database using RGBD camera, making the 3D scenes using them (Shao et al. 2012).

Interactive Layout Generation Using IEC

Color Design

Miki et al. proposed the office design system that uses PDIGA (Miki et al. 2003). The system optimizes the color of office equipment and supplies such as partitions, carpets, tables, personal computers, and chairs. Genes represent the continuous-valued hue and tone, and the system employs the real-coded GA method. The user evaluates the presented color pattern in terms of the preference and a style that suits the working environment using the five-level scale.

Floor Layout

Garcia et al. proposed the IGA-based system that generates the floor layouts of an ovine slaughterhouse and recycling carton plant incorporating the knowledge of expert designer and preference of the user (Garcia et al. 2013). The system uses the flexible bay structure that manages the floor layouts by dividing floor into bay. Genes represent the equipment number used to specify an equipment location and the position of a bay.

3D Room Layout

Akase et al. proposed the IGA-based system that generates the 3D room layouts by a combination of parent-child relationships (Akase et al. 2013, 2014). The system saves the combinations to the

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 6 The build process of combinations

```
maximum_number_of_furniture_objects = 37;
maximum_number_of_patterns = 8;
patterns[maximum_number_of_furniture_objects]
[maximum_number_of_patterns];
makePatternNumbers ( )
  i = 0;
  REPEAT
    object_i = select a furniture objects;
    pattern = {};
    //The system uses this number for genes
    pattern_number = 0;
    REPEAT
      //designer's task
      pattern.parent = select a parent object;
      //designer's task
      pattern.relative_distance = set a
relative_distance;
      //designer's task
      pattern.relative_angle = set a relative_angle;
      patterns[i][pattern_number] = pattern;
      pattern_number = pattern_number ± 1;
    UNTIL
pattern_number > maximum_number_of_patterns;
    i = i + 1;
  UNTIL i > =
maximum_number_of_furniture_objects;
STOP
```

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 7 The build process of room layout

```
maximum_number_of_furniture_objects = 37;
//idx is the index number of an individual
gene_sequences[idx]
[maximum_number_of_furniture_objects];
placeObjects (gene_sequences, patterns)
  i = 0;
  REPEAT
    //select a pattern number (gene element) from a gene sequence
    pattern_number = gene_sequences[idx] [i];
    //get a pattern data
    pattern = patterns[i] [pattern_number];
    //The root parent is "Room"
    IF pattern.parent is not placed THEN
      i = i + 1;
      continue;
    ENDIF
    //place a target object_i
    object_i.position = pattern.parent.position + pattern.relative_distance;
    object_i.rotation = pattern.parent.rotation + pattern.relative_angle;
    i = i + 1;
    IF i > maximum_number_of_furniture_objects THEN
      i = 0;
    ENDIF
  UNTIL all objects are placed;
STOP
```

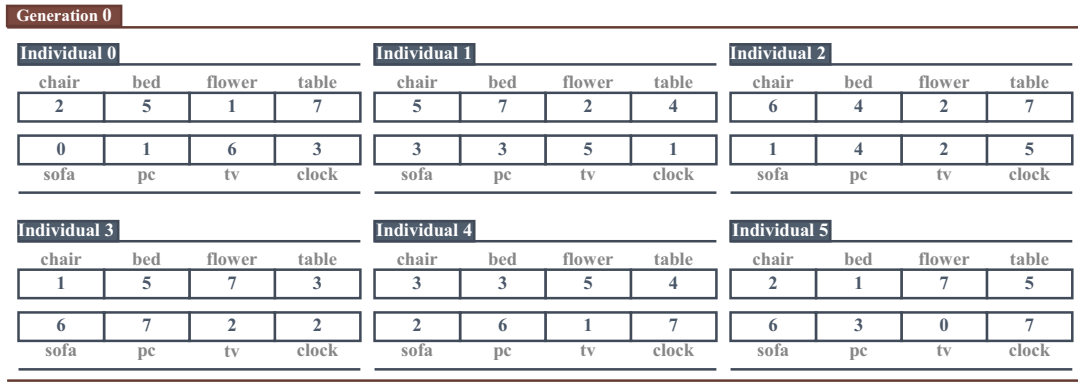
database as with the system Akazawa et al. proposed. Table 6 explains the build process of combinations, and Table 7 shows the build process of room layouts. Genes represent the combination index called "pattern number." Figure 3 illustrates an example of gene sequences, and Fig. 4 indicates a part of evolving process in order of top left to bottom right. It optimizes 3D room layouts based on user evaluations.

Quantitative Evaluation Techniques and Problems of the IEC-Based Systems

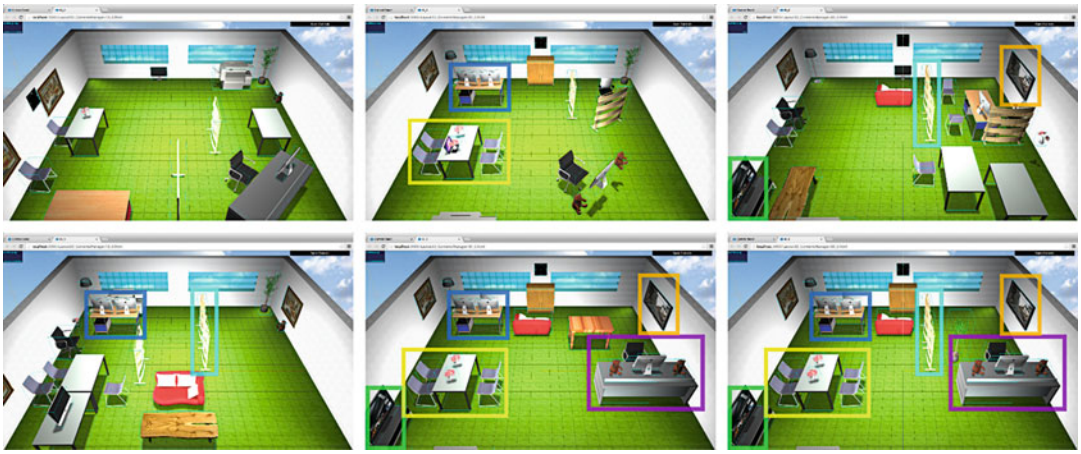
Quantitative Evaluation of the IEC-Based Systems

It is difficult to measure performance of the IEC-based system in a quantitative way because it includes the subjectivity of users. Many studies perform a perceptual study using actual users to receive a questionnaire about the usability and logs of fitness, and they evaluate the usefulness of the IEC-based system applying a statistical test to them. The following are specific assessment procedures:

1. Set the goal individual (concept) users should create.
2. Conduct the experimental tests using actual users.
   (A) Create the goal individual using an authoring tool manually.

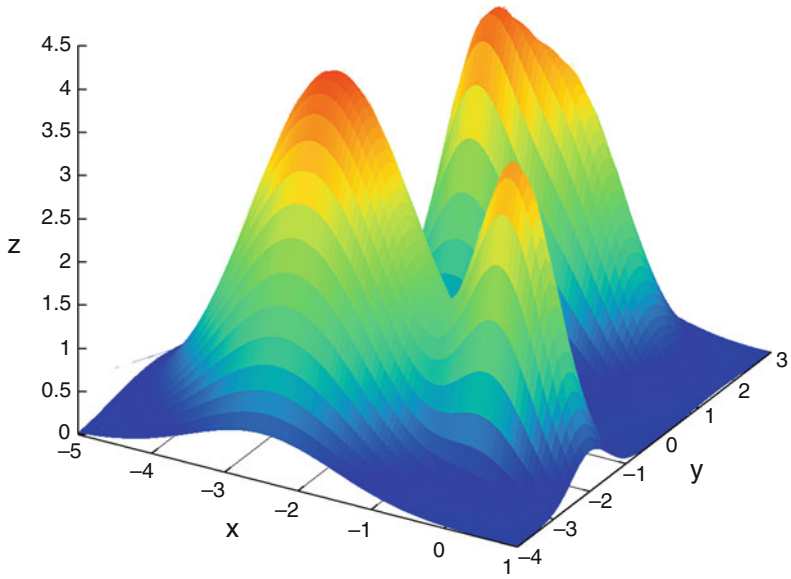


3D Room Layout System Using IEC (Interactive Evaluational Computation), Fig. 3 An example of gene sequences



3D Room Layout System Using IEC (Interactive Evaluational Computation), Fig. 4 A part of evolving process in order of *top left* to *bottom right*

3D Room Layout System Using IEC (Interactive Evaluational Computation), Fig. 5 Mixture Gaussian function



(B) Create the goal individual using the IEC-based system interactively.

3. Subjects select A or B that let them create the goal individual easily.
4. Calculate statistically significant difference between A and B.

Takagi et al. proposed a performance evaluation method for IEC algorithms (Takagi et al. 2009). It represents a psychological peculiarity of an IEC user using a mixture Gaussian function consisting of four Gaussian functions. The following are specific function and parameters, where n is the dimension number (Fig. 5):

$$\mathrm{f}\left(x_1, \ldots, x_n\right) = \sum_{i=1}^{4} a_i \exp\left(-\sum_{j=1}^{n} \frac{\left(x_{ij} - \mu_{ij}\right)^2}{2\,\sigma_{ij}^2}\right)$$

$$\mathrm{a} = \begin{pmatrix} 3.1 \\ 3.4 \\ 4.1 \\ 3 \end{pmatrix},$$

$$\mu = \begin{pmatrix} -1 & 1.5 & -2 & -2.5 & -1 & 1.5 & -2 & -2.5 & -1 & 1.5 \\ 0 & -2 & 3 & 1 & 0 & -2 & 3 & 1 & 0 & -2 \\ -2.5 & -2 & 1.5 & 3.5 & -2.5 & -2 & 1.5 & 3.5 & -2.5 & -2 \\ -2 & 1 & -1 & 3 & -2 & 1 & -1 & 3 & -2 & 1 \end{pmatrix}$$

$$\sigma = \begin{pmatrix} 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 & 1.5 \\ 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 \end{pmatrix}$$

Problems of the IEC-Based Systems

The maximum limit both of the number of individuals and generations is around 10–20 due to a burden of the user evaluation effort in the IEC-based systems (Takagi 2001; Takagi et al. 2009). Therefore, developers have to consider the following:

1. Improve the convergence speed of group of individuals.
   - In general, it depends on an evolutionary computing algorithm.
2. Support the user evaluation effort.
   - Improve the IEC user interface and evaluation method.
   - Incorporate an agent that predicts the fitness based on the characteristics of IEC users.

The effective algorithms such as PDIGA, IDE, and their derived type are addressing the first problem as the previous section explained. This section introduces some support methods to reduce a burden of the user evaluation.

Improvement of the IEC User Interface

The system Garcia et al. proposed clusters individuals, and it displays some representative individuals to the user at least in the early generations (Garcia et al. 2013). It employed the fuzzy c-means clustering algorithm (FCM) Bezdek et al. proposed (Bezdek et al. 1984). Each individual can belong to some clusters because the FCM allows overlapping of clusters. This feature can help the user evaluation because the individuals that the user did not evaluate can get scores from evaluated individuals belonging to a same cluster.

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 8 The procedure of proposed system

```
MAIN ( )
  p = predefined weighting coefficient;
  priorities, elite = CONJOINT_ANALYSIS ();
  generation = 0;
  create initial group of individuals;
  REPEAT
    //Function C checks the constraints associated with priorities
    fitness = (1 – p) * priorities * C (current group of individuals)
      ± p * USER (current group of individuals);
    IF user is satisfied THEN RETURN the best individual;
    i = 0;
    REPEAT
      select two individuals based on fitness;
      //maintain upper two individuals
      apply elitist selection;
      //produce new two individuals
      perform crossover;
      //produce new two individuals based on the elite individual
      perform crossover with elite;
      perform mutation;
      insert six offspring into new group of individuals;
      i = i + 6;
    UNTIL i > predefined number of individuals;
    generation = generation + 1;
  UNTIL generation > predefined number of generations;
STOP
```

3D Room Layout System Using IEC (Interactive Evaluational Computation), Table 9 The procedure of conjoint analysis

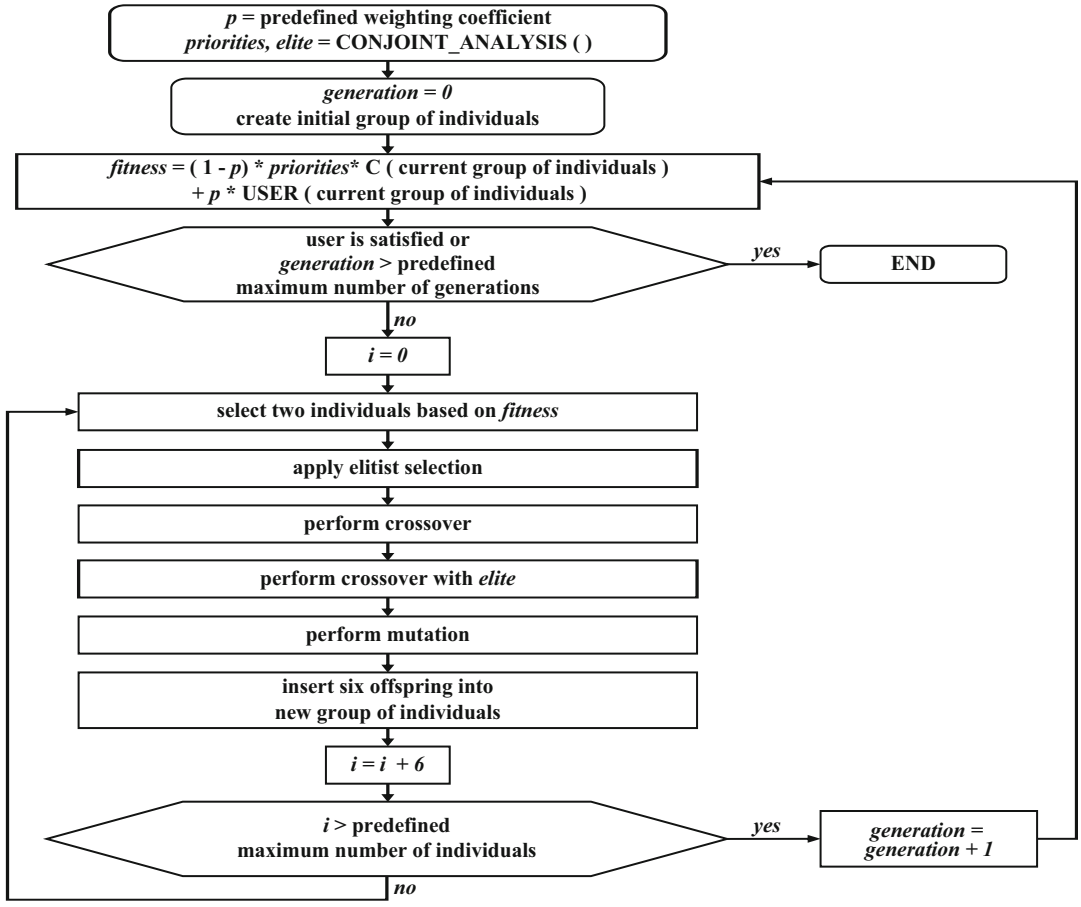
```
CONJOINT_ANALYSIS ( )s
  cards = predefined renderings;
  REPEAT
    scores = USER (subset of cards);
    averages = calculate_average (subset of cards, scores);
    deviations = calculate_sum_of_squared_deviation (subset of cards, scores, averages);
    products = calculate_sum_of_products (subset of cards, scores, averages);
    solution = solve_system_of_equations (deviations, products);
    priorities = calculate_priority (solution);
    expectancies = calculate_expectancy (cards, solution);
    elite_individual = select_best_card (cards, expectancies);
    precision = check_precision (scores, expectancies);
  UNTIL precision > = 0.5;
  RETURN priorities, elite_individual;
STOP
```

Analysis of the Characteristics of IEC Users

The system Akase et al. proposed analyzes user preferences using a conjoint analysis so that it can support user evaluations and reflect user preferences effectively (Akase et al. 2014). The conjoint analysis is an experimental design method that gets user evaluation values from some rendering and returns the characteristics of users. Tables 8 and 9 and Fig. 6 explain the procedures of the proposed system. The system generates offspring around the elite individual selected by the conjoint analysis. In addition, the individual that fits the potential user preference analyzed by the conjoint analysis gets an additional score from the system automatically. These features can accelerate the convergence speed.

Summary

This entry introduced the typical IEC algorithms, generation methods of layout, and recent IEC applications. In addition, it indicated the problems of the IEC-based systems and some solutions for future directions. Although the burden of the user evaluation to optimize complex contents such as 3D room layout that has many parameters is a problem, many researchers are addressing it. An IEC-based authoring tool could be a practical product if they resolved the problem completely.



3D Room Layout System Using IEC (Interactive Evaluational Computation), Fig. 6 The flowchart of proposed system

Cross-References

- Character Animation Scripting Environment
- Genetic Algorithm (GA)-Based NPC Making
- Teaching Computer Graphics by Application

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A

3D Selection Techniques for Distant Object Interaction in Augmented Reality

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Synonyms

Augmented reality; Distant object; Selection techniques; User interaction

Definition

Selection is a prerequisite task for object manipulation in 3D user interfaces. The virtual object must obey specific conditions to be considered the targeted object for selection. This article explores the existing selection techniques for the

distant object in an augmented reality environment.

Introduction

Recently, augmented and mixed reality (AR/MR) application has become more popular among researchers, businesses, and developers in presenting the information. As current technologies have improved and are capable of AR and MR, more interesting and improved applications are developed to meet users' needs. In AR and MR, selection has been the common task in performing interaction with virtual objects that is being superimposed on the real-world environment. According to Mine (1995), selection is considered when an object is being pointed and validated among other objects available. The selection is important to be precise in order to select the targeted object in the scene correctly. Therefore, various approach has been taken by the previous researchers in order to overcome this issue. Meanwhile, according to Yin et al. (2019), the issue of defining suitable and propitious 3D interaction techniques is still an agile area of study.

Milgram continuum, a reality-virtuality continuum, has sufficient reference for the framework regarding the classification of different immersive technologies. The continuum depicted MR as a transition between the actual and virtual worlds, including AR with augmented virtuality (AV) placed in between (Milgram and Kishimo 1994). The blending of real and virtual worlds creates new surroundings and visualizations, allowing for an immersed user experience, which refers to the quality of the interactions given to the user. Meanwhile, AR enables the visualization of virtual objects in conjunction with real-world scenes via mobile devices such as smartphones and tablets, including AR glasses and head-mounted displays (HMD) (Silva 2018).

With the current advanced technology, AR applications in mobile devices are more approachable, allowing them to bloom and enable various applications widely. In the early stage of AR, AR was first used for entertainment in the form of games. Still, it is now being used in a variety of areas, including education, healthcare, training, remote collaboration, maintenance assembly, and smart manufacturing (Barrie et al. 2019; Birt et al. 2018; Peña-Ríos et al. 2012; Richert et al. 2019; Stretton et al. 2018). Selection for the target object in AR and MR will allow the interaction to be more precise and therefore enable a more complex interaction within the application.

In this context, this article presents and discusses the overview of the selection techniques proposed by previous researchers for the target object in MR to improve the interaction between the users with the target object in the environment.

Background

3D interaction techniques have been extensively researched in immersive virtual environments using HMDs and tracking devices, including data gloves and on desktop setups with a keyboard and mouse (Yin et al. 2019). Bowman et al. (2004) investigated the interaction techniques commonly used in 3D user interfaces and created a taxonomy of universal tasks for interacting with 3D virtual environments: selection and manipulation of virtual targets; navigation and path findings inside a 3D environment; giving instructions using 3D menus: text, tags, and legends are examples of symbolic input. Meanwhile, several studies have explored the attributes that improve the usefulness of 3D user interfaces, mainly for desktops and near-to-eyes displays. They have proposed a general guideline to UI developers. Better use of depth cues, especially occlusion, shadows, and perspectives, as well as considering the constrained angle of the viewpoint position, object being in contrast with the surroundings, and other factors, are included among the guidelines.

Therefore, accurate selection plays an important part in providing education and information exchange among academics, companies, and developers. For a more pleasant overall experience, applications like entertainment and gaming require more interaction for the user. While for

commercial uses such as healthcare or business training, there is a need for a feeling of physical presence to be more effective with the interaction and enable accurate selection.

Several input alternatives currently exist and has been proposed by previous researchers in performing selection and further interaction with the virtual objects such as touchscreen-based inputs, gesture-based input, inertial device-based input, speech-based inputs (Lee and Chu 2018; Mossel et al. 2013; Połap 2018; Su et al. 2018; Yusof et al. 2020). However, gesture-based input is described as the most natural and intuitive approach in performing selection to interact with the virtual object. Interaction with natural gestures in free space enables possibilities for exploiting the interaction's fullness and expressive-ness, allowing the users to manage several things at once with more degree of freedoms (DoFs) and utilize the familiar and real actions (Argelaguet and Andujar 2013). Furthermore, interaction using natural gestures is the most familiar action for the users, which mimics the actions in daily life.

Besides that, the brain-computer interface (BCI) is another field that has sparked researcher's interest in enabling a new way of interaction in the AR/MR environment (Si-Mohammed et al. 2017). BCI is a system that takes a biosignal, measured from a person, and predicts (in real-time) certain aspects of the person's cognitive state. BCIs could particularly contribute to AR-based systems interaction means, especially on visual selection tasks that can be done, as an example, via steady-state visually evoked potentials (SSVEP) or P300 (Gergondet et al. 2011). With the high computational power of current computers and display devices, the goal to build a real-time adaptive system for AR has been made a lot more reachable (Vortmann 2019). Recently, the NextMind (www.next-mind.com) company has developed an affordable brain device with a novel type of SSVEP stimuli that is less straining on the eye. For example, Pietroszek et al. (2021) has utilized NextMind within their experiment with AR HMD to allow for derogating experience, where the player picks up and moves the pieces and rolls the dices using their brainwaves as input. With the availability of such device/technology, more possibilities of interaction or other research intention can be explored in various fields with the implementation of AR and MR.

There are various reasons on precise selection for the distant object is needed. Since AR and MR are becoming more prevalent in data or information presentations, it is essential to provide an accurate selection for better interaction between the user and the object in the system provided. To define precise selection, the time taken for the selection to be complete should be less, enabling a higher speed for the interaction to complete. With accurate selection, a more precise result of the interaction can be provided.

However, previous researchers have addressed several challenges on achieving selection for smooth interaction with the virtual object. Whitlock et al. (2018) have addressed interacting with distant objects in AR. Aside from that, pointing accuracy may be affected by variations of in-depth perception for real and virtual objects (Whitlock et al. 2018). Ro et al. (2019) also highlight the issue of selection on a distant object with limitations on devices such as see-through HMD (e.g., Hololens), where it requires the object to be within reach (limit distance reachable by the user) for it to be selected. Other challenges are that pointing to obscured target objects in noisy surroundings may need nonlinear visual and spatial mapping (Olwal and Feiner 2003). Therefore, previous researchers have proposed various approaches to address these issues.

The following section discusses the approaches from previous researchers on the selection techniques for a target object in AR/MR to enable and improve the interaction between the user and the target object in the environment.

3D Selection Techniques

According to the study by Argelaguet and Andujar (2013), interaction is more physically challenging within the 3D environment and may

obstruct user tasks by requiring greater skill. Their study has identified two main 3D selection metaphors: virtual hand and virtual pointing. The virtual hand is a common metaphor for interacting with objects in an immersive environment. It enables interactions with objects, which are within the arm's reach of the user. With virtual hand metaphor, objects are being interacted with in a manner that is similar to touching and grasping in real life. Virtual hands are often implemented as a one-to-one mapping of the user interaction area (the region of space that the user may reach, such as within arms reach of the user) and the control area (the space reachable by a virtual hand in the immersive system). On the other hand, virtual hands are typically less accurate and result in delayed task completion than the alternative technique, virtual pointing, owing to existing technology implementations.

Although the virtual hands technique is well-known at the beginning since it directly maps the virtual tasks identically with the actual task, which results in a more natural interaction. However, current researches have demonstrated that tackling real-world bodily constraints has significant advantages, such as allowing the selection on the out of reach objects to be performed by the user using raycasting, a pointing technique. According to a number of user analyses in the literature, virtual pointing techniques generally result in higher selection efficacy than rival 3D selection metaphors (Bowman et al. 2004).

Ray Pointing

The raycasting technique can be implemented for touch-based interaction, gesture-based interaction, or hybrid interaction. Raycasting can also be implemented in various aspects, including how the ray is being controlled. Raycasting extends the user's reach by pointing an extended ray outwards, starting at the user's hand or the designed cursor (Auteri et al. 2013). A starting point and a trajectory are required to control the ray. These two values may be obtained by monitoring the orientation and position of a controller, the hand of the user, head, or a combination of both. However, the most common approach is often by confirming selection with a button.

A study by Mossel et al. (2013) has presented DrillSample, which addresses the requirements for precise selection with a one-handed handheld interaction in a dense AR surrounding. Other than that, they also address issues of disambiguation and selection in a dense mobile AR environment for highly occluded objects or with high visual resemblance. In their approach to perform precise selection in touch-based interaction, a single touch action on the screen causes the coordinates of the 2D screen to be projected back into the 3D space. It will trigger the ray to be cast from the virtual camera's position in the direction of the 3D point into the handheld AR scene. The handheld device 6DOF stance, which is generally provided in handheld AR, may be used to estimate the direction.

Meanwhile, Ramos et al. (2015) presented GyroWand, a 3D interaction with the implementation of raycasting technique in independent AR HMDs. The inertial measuring unit (IMU) on a handheld controller captures relative rotation data utilized in the raycasting technique.

Another study by Ro et al. (2019) has proposed a new user interface that utilizes raycasting using the depth-variable method for selection on remote objects in an AR environment. The ray-depth information is included in addition to sensor information because ray-depth must be adjusted for pointing in mid-air in a 3D space. Although GyroWand is also utilizing IMU on a handheld controller to capture the relative rotation data for the raycast for the selection, however unlike the AR pointer, it did not have depth information. The GyroWand will go into the *Disambiguation state,* where users refine the actual target they want to select in-depth. Aside from that, the GyroWand was able to employ the ray as a line and convert it to a volumetric form if required. It will improve precision while choosing items at a distance.

Flexible Pointer

Apart from that, Olwal and Feiner (2003) have suggested a flexible virtual pointer that permits a user in a 3D world to more readily point towards

completely or partly covered targets and further clearly identify things to other users. The flexible pointer reduces ambiguity by avoiding concealing objects that might have been chosen if using traditional raycasting techniques. The flexible pointer is implemented as a quadratic Bézier spline, with three points (position, endpoint, and control point) in 3D space controlling its location, length, and curvature.

Go-Go Gesture Technique

Other than raycasting, Go-Go is another basic approach to perform selection on the target object (Poupyrev et al. 1996). Although Go-Go performs poorly in dense settings when picking objects, it can readily choose entirely occluded objects in a single step. In the Go-Go technique, the selection is done by extending the virtual hand towards the target object. A study by Jung et al. (2017) has proposed BoostHand in which they modify The Go-Go interaction technique into one that can be switched using easy trigger actions. The Go-Go interaction approach utilizes a preset mapping function to easily manipulate virtual objects with a virtual hand avatar. The interaction is intuitive and natural since it makes use of the natural hand, requires little training, and performs the functions of selecting (grabbing) and manipulating (translation, rotation, and scale) in real-time.

A study by Yin et al. (2019) has addressed the issue of selecting occluded target objects with touch-based interaction. Touch-based interaction is one of the most natural and attractive input forms for handheld interfaces because it allows users to interact directly with the target object. Other than that, they also address the issue of the small area for interaction, as the display screen is limited. Therefore, their study discusses four novel 3D selection techniques with Go-Go and Raycasting techniques as the baseline to overcome these issues. After pointing at an object at a distance (laser pointer metaphor) and intersecting the ray, the user may select the object using other actions (button selection, gesture, or speech) (Ro et al. 2019). However, it becomes less intuitive and natural than the real hand manipulation method.

Hybrid Technique

Meanwhile, a study by Kim and Lee (2016) proposed a hybrid interaction technique that combines touch-based with real hand gesture-based interaction to perform a selection for further interaction with objects in the environment. The selection of the AR object is completed with a touch gesture, while a real hand gesture is enabled for manipulation of the selected objects directly and interactively. As a result of the hybrid interaction, the user will be able to perform interactions such as manipulation on the AR targets in actual 3D space rather than 2D space.

Due to calibration flaws and tracking system constraints, eye gazing may be quicker and more ergonomic for selecting the target object, but it has poor precision. As a result, researchers have developed multimodal techniques that improve eye-gaze selection using a supplementary input modality that will refine the selection process. For example, the target selection technique presented by Kytö et al. (2018) implements selection techniques with a multimodal approach, using eye-gaze or head-motion. To achieve pinpoint precision, these techniques use rough pointing selection accompanied by a secondary, local refining action. Each primary selection mode is able to combine with any refinement method. Their research is limited to 2D surfaces, such as those implemented in selecting the menu, interactive visualization, and in-situ CAD application.

Furthermore, multimodal input is seen as a way to increase the interactions of virtual and real-world components. Because it allows for simultaneous interaction within the physical and virtual worlds, the interaction approach is suitable for AR applications (Ismail and Sunar 2015). Meanwhile, speech input is often implemented as a hybrid technique combined with gesture-based or gaze-based for interaction with objects in AR and MR environments. Speech has been shown to be an ideal choice for abstract actions, such as selecting a device among many devices or interacting with multi-object (Piumsomboon et al. 2014; Zaiţi et al. 2015). The advantages and drawbacks of the 3D selection techniques of related researches discussed in this article are summarized in Table 1.

3D Selection Techniques for Distant Object Interaction in Augmented Reality, Table 1 The summary of 3D selection techniques of related researches

Researchers	Proposed selection technique	Advantage	Drawback
Ro et al. (2019)	AR Pointer – Able to specify ray direction and adjustable ray's depth to calculate the ray's endpoint	Easy to learn for the user and fast completion time Able to register an object at a specific mid-air point in three dimensions	The error rate is higher for object rotation angle error (arc ball rotation method)
Yin et al. (2019)	Present four novels AR selection techniques for handheld mobile devices.	Although tested in a handheld AR environment, it can also be applied in other dense virtual environments or other interactive interfaces that use touch screen input	The technique presented was only implemented for selection using touch-screen input
Kytö et al. (2018)	Multimodal pointing techniques for wearable AR interfaces. Presented two prototypes – GazeBrowser and SmartPupil	Include two primary input modes, eye gaze and head pointing, and combine with a refinement provided by a handheld device	Gaze calibration was typically less accurate for extreme upper and lower targets, and that overall accuracy tended to degrade over time
Jung et al. (2017)	BoostHand – a freehand, distance-free object-manipulation system that supports simple trigger gestures using Leap Motion	The user control space can be expanded by emphasizing intuitive and straightforward interaction Able to provide better performance at long distances with fewer movements	Tracking errors by Leap Motion can largely influence the system's performance
Kim and Lee (2016)	Hybrid interaction of touch-based and real hand gestures for direct interaction with AR objects	Enable natural and intuitive interaction with 3D AR objects on handheld and mobile devices	One hand needs to hold the device, which could lead to fatigue.
Ramos et al. (2015)	GyroWand – interprets the relative rotational values using a state machine and provide three new disambiguation mechanisms	Initiate raycasting from other spatial coordinates (chin is a good candidate as the origin for the raycast)	Does not investigate the performance and comfort of the proposed approach against the natural user interface
Piumsomboon et al. (2014)	G-SIAR – multimodal interaction technique of gesture and speech	G-Shell required less effort, frustration, mental, physical, and temporal demand, and provided higher performances	There are limits in the tracking resolution and speech and gesture recognition accuracy
Auteri et al. (2013)	Presented a hybrid selection technique that combines PRISM and Go-Go	Enumerated different design decisions involved blending PRISM and Go-Go, resulting in a huge improvement in task precision	The user felt a lack of control when using PRISM
Mossel et al. (2013)	DrillSample – two-step selection technique with only one finger input in a dense handheld environment (high visual similarities)	Develop guidelines to enable precise selection in a single-handed handheld AR environment The performance study clearly revealed the strength of the DrillSample technique compared to related work in the study	It was only tested for selection on the occluded object within close range

Conclusion

Over the last decade, the topic of selection on the target object has been in the interest of researchers and developers from various fields of studies in AR and MR. It shows that selection still plays a vital role in interaction with the target object in AR or MR environment.

Selection as the basic task in performing interaction with the virtual object must be as precise as possible. With preciseness, it will allow a faster and smoother interaction between the user and the virtual content. Selection techniques can be provided in several techniques such as raycasting, Go-Go, or hybrid techniques. Raycasting is a technique for aiming objects from afar with limits for object manipulations like translation and rotation. Meanwhile, Go-Go produces better results when selecting the occluded target object. However, a hybrid technique such as combining touch-based and gesture-based for selection and further interaction with the target object could offer an intuitive and regular interaction in the AR surroundings. While in the MR interface, occlusion becomes an issue when real hands have covered the virtual object. As an advanced selection, Aladin et al. (2020) has explored the occlusion-hand gesture in MR to perform a precise selection technique using the real hand gesture in MR.

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3D Simulation

▶ Nursing Education Through Virtual Reality: Bridging the Gap

3D Skills

▶ Training Spatial Skills with Virtual Reality and Augmented Reality

3D User Interfaces

▶ Natural Walking in Virtual Reality

3D Visualization

▶ Technologies for the Design Review Process

3D Visualization Interface for Temporal Analysis of Social Media

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Definition

3D visualization interface for temporal analysis of social media is the interface for visual analytics of various types of time varying media

contents using 3D information visualization techniques.

Introduction

Social media such as blogs and microblogs has become popular. It enables us to easily and rapidly publish information on our personal activities, interests, and opinions through writing document, creating links to other information resources, and providing images and/or movies. It dynamically reflects real movements in society.

Many organizations have collected and archived social media contents over the long term. Time series of archived data enable us to analyze temporal changes in trends in social media that reflect both real and virtual activities.

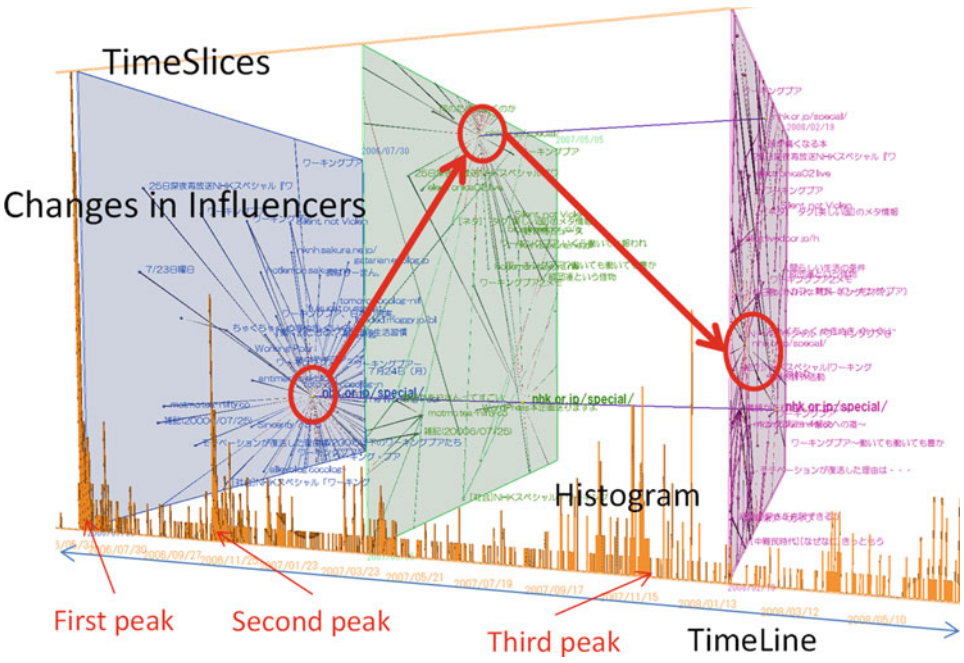
Visual analytics for extracting trends and reading stories from time sequential data sets are important research domains. There has been much research on analyzing temporal changes in trends on social media through visualizing link structures, results of text analysis, or flows of images (Kitsuregawa et al. 2008; Chi et al. 1998; Chi and Card 1999; Toyoda and Kitsuregawa 2005; Kehoe and Gee 2009).

In this entry, I will introduce three kinds of 3D information visualization systems for analyzing temporal changes in: (i) link structure, (ii) textural contents, and (iii) image contents on social media.

State-of-the-Art Work for Visualizing Temporal Changes in Social Media Contents

Visualization for Temporal Changes in Link Structure

We first introduce an interactive 3D visualization system for the time series of web graphs (Itoh et al. 2010). It is to enable us to examine the evolution of web graphs by comparing multiple graphs that have different timings and topics. To accomplish the system, it utilized interactive 3D components called TimeSlices that are 2D planes to visualize web graphs in a 3D environment. We



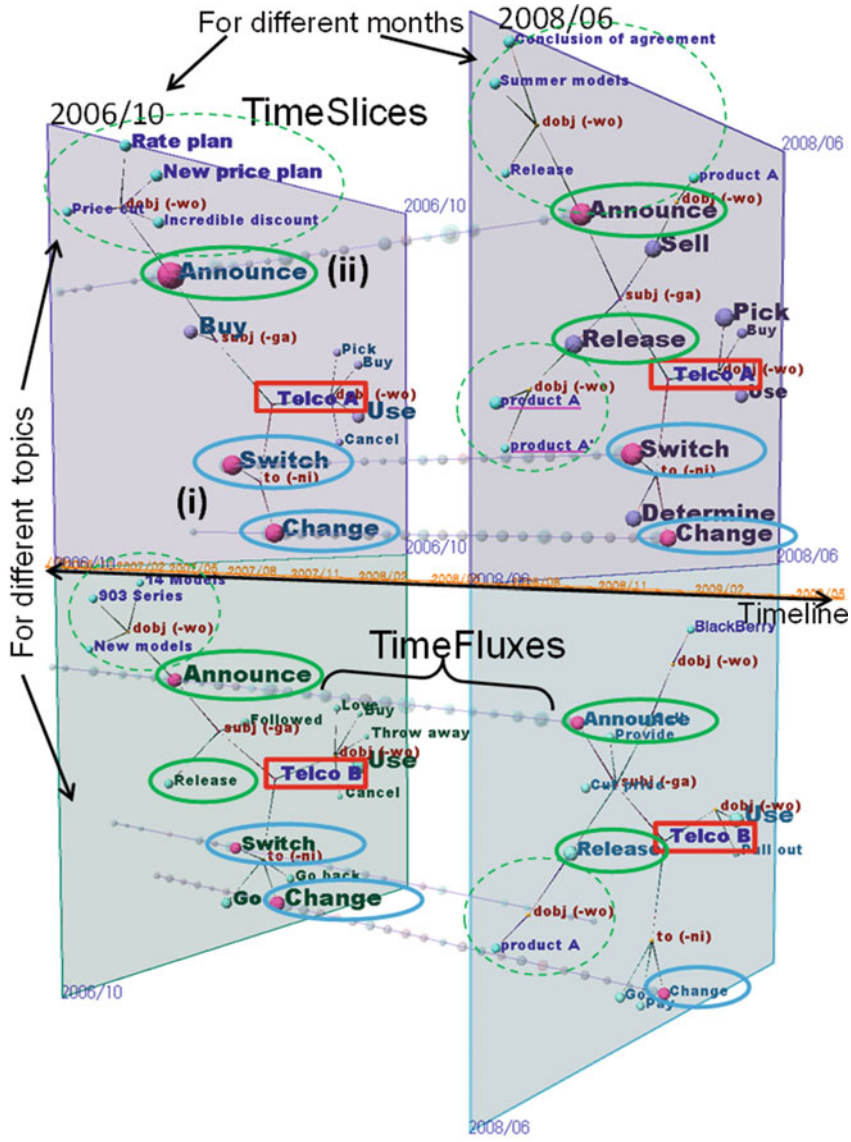
3D Visualization Interface for Temporal Analysis of Social Media, Fig. 1 Example for visualizing changes in link structure on blogs related to the term "working poor"

can interactively add new TimeSlices along the timeline, and they can manipulate them to animate web graphs. Visualized web graphs on TimeSlices are snapshots of different timings.

Figure 1 shows the example for visualizing changes in link structure on blogs related to the term "working poor." First peak appeared after the TV program called the "working poor" had been broadcast. Most blogs were linked to the official page of the TV program. The second peak appeared after the "working poor II" had been broadcast. We can find that influencers shifts in focus from the official pages of "working poor" to "working poor II."

Visualization for Temporal Changes in Textural Contents

We next introduce an interactive 3D visualization system for exploring temporal changes in bloggers' activities and interests through



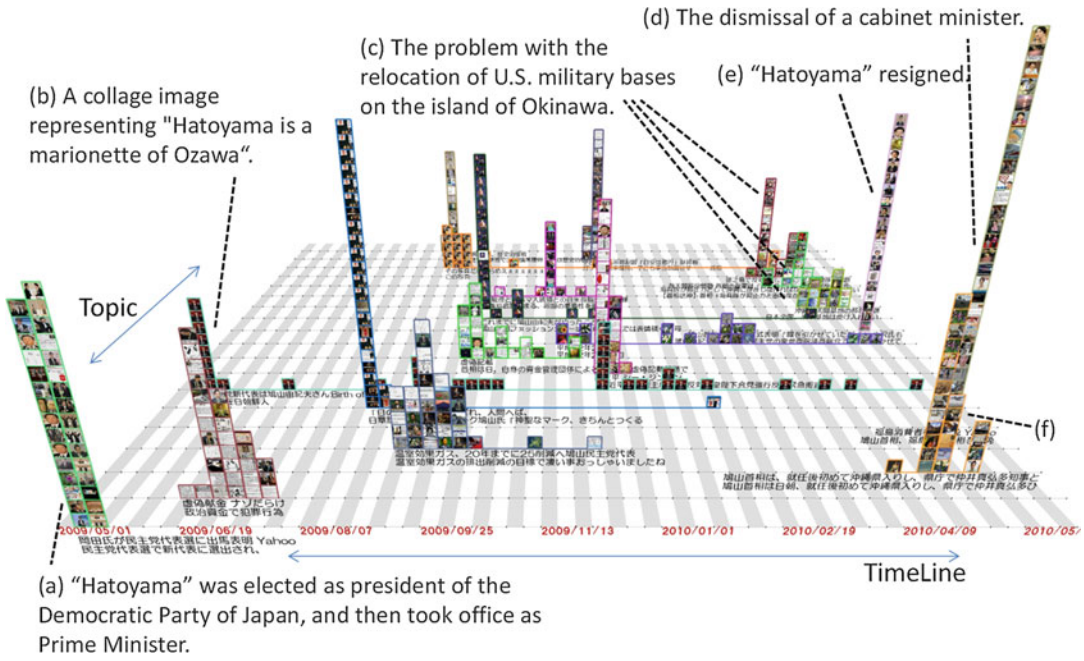
3D Visualization Interface for Temporal Analysis of Social Media, Fig. 2 Example for visualizing changes in textural contents on blogs for comparing marketing effect of two telcos

visualizing phrase dependency structures (Itoh et al. 2012). To accomplish the system, it utilizes two 3D components such as TimeSlices and TimeFluxes. TimeFluxes enable us to visualize temporal changes in the attribute values of particular nodes at every timing. The system visualizes dependency structures of phrases as a unified tree representation in TimeSlices and enables us to interactively navigate to the detailed information by expanding nodes in the tree representation. Sliding operation for the TimeSlices along the timeline indicates changes in the structure and frequencies of dependency relations. To compare different timings and topics side by side, it provides multiple 2D planes. It also visualizes changes in the frequencies of dependency relations by using TimeFluxes.

Figure 2 shows the example for visualizing changes in textural contents on blogs for comparing marketing effect of two telcos. The upper TimeSlice shows a topic for "Telco A," while the lower one shows a topic for "Telco B." (i) We can recognize events related to "change/switch to Telco A" are more popular than "change/switch to Telco B" in most months by observing changes in the structure and frequencies for events. (ii) We can expand nodes related to "announce" and "release" to find details on announcements and products that were released, and we then find that "Telco A" announced a "new price plan" in the first peak and released "product A" in the second peak.

Visualization for Temporal Changes in Image Contents

We finally introduce a 3D system for visualizing visual trends on social media that chronologically displays extracted clusters of images on blogs (Itoh et al. 2013). The system first adopts a histogram of images by stacking them on a timeline to visualize the flow of various images at each timing to visually analyze trends. This design enables us to find the timing for the beginning of the topic, changes in trends for the topic, bursting points, and a lifetime of the trends. Secondly, it arranges multiple histograms of images in a 3D space to visualize images on different aspects. This design allows us to observe different situations between



3D Visualization Interface for Temporal Analysis of Social Media, Fig. 3 Example for visualizing changes in clustered images related to "Prime Minister Hatoyama" extracted from blogs

different topics, sequences of trends, and events with the same timing on different topics.

Figure 3 shows the example for visualizing clusters of images related to "Prime Minister Hatoyama" extracted from blog based on visual, textual, and chronological similarities. The top 20 clusters are arranged from front to back according to their rankings. Images are aggregated per week. We can read stories about "Prime Minister Hatoyama" by exploring the movements of topics.

Conclusion

This entry has introduced the 3D visualization systems for analyzing social media that utilized one dimension in a 3D space as a timeline. Although they independently visualized temporal changes in link structures, results of text analysis, and image clustering for single medium, we can combine these contents and mechanisms to construct integrated 3D visualization systems for intermedia analysis.

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3D-Rendered Images and Their Application in the Interior Design

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Synonyms

Depth of field; Interior design; Length of view; Lens; Real estate photography; Render; Virtual camera; V-ray, 3D studio max

Definitions

Aperture	This is the hole through which light enters the camera. Its size can be changed to control the brightness of the light allowed through to the image sensor.
Depth of field (DOF)	It determines the depth of field as a range of scene depths that appear focused in an image.
Field of view (FOV)	It illustrates what angle is captured by the lens. The size of the FOV is designated in mm.
Rendering	The process of image synthesis by simulating light environment. The rendering process is performed by render plugins.
Shutter	The shutter speed setting determines how long the shutter remains open to expose the image sensor, e.g., it controls the length of the exposure.
V-ray	It is a render plugin which adds some additional features to the existing software such as: 3D Studio Max, Maya, Blender, Rhynoceros 3D.

V-ray Physical Camera	The camera is the tool that captures virtual 3D image/s.

Introduction

Many interior designers aim to improve the effectiveness of their workflow by reducing the workload they spend to prototype certain products and to dramatically increase the "wow" effect of their final output. The creation of a "dream home" is a major goal to every practitioner whose projects reflect the clients living preferences by lining up shapes, forms, color palette, finishes, textures, and lights. Our fast-paced digital life has changed the consumer's perception and requirements by making it much more sophisticated. The traditional two-dimensional hand-drawing sketches provide certain restrictions regarding the client's imagination by not being able to realistically recreate the real space.

However, the hand-drawing rendering (sketches) laid the basis of the contemporary 3D design and they facilitate the interior designers in building the main foundation of their projects (Wang 2002, p.12): "The real understanding of pencil sketching goes beyond the "state of the art" – it is about creative seeing, such as how to isolate or highlight details in a complex visual scene." Sketching plays a significant role in designer's eye-hand coordination (Wang 2002). People naturally see, observe, and create their projects and the pencil sketching enable the designers to conceive some fresh concepts and to come up with innovative ideas. Thus, sketching as a method could be deemed as a vital prerequisite stage of the workflow rather than an "obsolete" and useless approach.

Recently conducted research study, published by marketsandmarkets.com argues the 3D rendering is expected to grow in a frenetic rate: from USD 1.06 billion in 2017 to accumulate USD 2.92 billion by 2022, at a compound annual growth rate (CAGR) of 22.40% during the forecast period. Many experts are convinced that the usage of 3D visualizations refine the interior design projects as a real showcase of what actually the future home could be without any distortions or including some redundant details.

In order to explore the application of 3D-rendered images in the interior design is important to explain the 3D rendering as a process.

In the real world, the light sources emit photons that travel in certain direction until they interact with a surface. When the photon hits a side, it might be absorbed, reflected, or transmitted. Some of the photons that hit the retina of the viewer are converted into a signal that is perceived by the brain and thus – creating an image. The creation of an image which is based on the same interaction between photons and a 3D environment might be simulated on the computer. The process of image synthesis by simulating light environment is called rendering (Walia 2010). An array of research has been conducted, focused on the following problems:

- How to achieve high quality rendering that induces the feeling of photo realism?
- How to reduce the rendering time?

Rendering Techniques

However, the rendering techniques could be classified into two main approaches (Verma and Walia 2010):

- Geometry-based rendering – the illumination of a scene has to be simulated by applying shading models. This method requires more computing power.
- Image-based rendering – using images as a modeling primitive.

Principles in the Interior Design

The initial stage of project planning includes planning of partitions, furniture layouts, finishes, etc. This process is based on following some specific rules which might seem quite universal for all types of design, e.g., graphic design, fashion design, etc. These rules are determined by Erica Swanson as: balance, emphasis, proportion and

scale, harmony and unity, the rhythm (Swanson 2010).

- Balance
- Emphasize
- Proportion and scale
- Unity and harmony
- Rhythm

Experienced designers often break these rules or create their own in terms of what they insist to achieve. However, in order to illustrate the final outcome, the real estate marketing utilizes the photography as an appropriate manner to present the completed property and its features. The investigator illustrates below the ten most essential and vastly popular principles in real estate photography, determined by Lohrman (2014):

1. Clearly illustrate the features of the estate.
2. Use wide-angle lens.
3. Remove the clutter shadow.
4. Take a primary exterior shot.
5. Illustrate the interior as light and bright – it refers to the exposure control settings.
6. The property's walls must look straight.
7. Vertical and horizontal lines must be also straight.
8. Avoid the brightness of the windows which causes distraction.
9. Simplify the color palette.
10. Present the photo in the most effective way.

The usage of 3D software could facilitate the implementation of these principles by assuring a set of tools that allows designers create, modify, insert objects and textures, adjust the lighting scheme, point of view, and render the final image in a resolution that is suitable for different purposes. Moreover, the 3D modeling and rendering could provide clients with more realistic perspective of the space, to let them decide whether certain furniture fits with the space or not as well as to identify certain flaws. Once these faults are identified, the designers could discuss with their clients how to resolve the problem and come up with an appropriate solution without losing time later.

By using 3D renders, interior designers would be able to simulate how different furniture, finish, wall textures interact with the environment and the main light sources.

3D modeling and texturing enable interior designers easily adjust the space, colors, lights sources, and textures according to clients' preferences. Furthermore, the 3D modeling and rendering allow relatively quick customization and modifications after receiving the clients review. This process significantly increases the effectiveness of the interior design by facilitating the relationships between designers and clients.

However, rendering algorithms are rather complicated and the accomplishment of high realistic 3D images often could be a highly time-consuming process. It might require some special hardware features, based on the fact that rendering time is highly dependent on scene complexity. As a consequence, interior designers should be very careful when choosing the right render engine.

What Is V-Ray

V-ray is a render engine, which means it adds some extra features to the existing software such as: 3D Studio Max, Maya, Blender, Rhynoceros 3D, etc. by improving the render speed and quality. This render engine aims to create photo-realistic images for the needs of the interior and exterior design, product design, and animation. This entry exams the V-ray as a plugin to 3D Studio Max and all examples are produced in 3D Studio Max. However, the Render Setup menu allows to set up the right render – Mental Ray, V-ray, or V-ray RT. The last one enables its users to utilize both CPU (central processing unit) and GPU (graphic processing unit) hardware acceleration and to see the update to the render while they edit the scene in real time (lights, materials, textures, camera, etc.).

Regarding the functionality of V-ray, this render engine provides users with its own lights and camera.

V-ray lights include a set of lights that are specially designed for application in 3D Studio Max. The standard Ray Traced Shadow and

Shadow Map shadows are optimized to work with V-ray. However, V-ray offers its users with a V-ray Light Meter Utility that enables them to evaluate the lighting in a scene and to make certain adjustments in order to refine the lighting. Depending on the effect designers want to create, they could use some of the following lights, determined by CHAOS GROUP (http://docs.chaosgroup.com):

- Area lights – V-ray light that can be used to create physically accurate area lights of different shapes. Designers could choose some of the following types of shapes: plane light, disc light, sphere light, mesh light, and dome light.
- A Sun light – designed to work together, V-ray Sun and V-ray Sky reproduce accurately the real-life Sun-Sky environment.
- Photometric lights – it enables the users to utilize *.ies files* – it is a file which contains specific features of a real-world light bulb.
- Ambient light – this light does not come from specific directions and it could be used to reproduce or simulate global illumination.

The accurate usage of the above-explained lights would allow interior designers establish a full-fledged 3D scene and enable them to customize precisely the lighting effects they intend to create.

V-Ray Physical Camera

However, a 3D photo realism could not be possible without using an appropriate camera. The camera is the tool that captures the image/s and enables the cameraman to tell stories. Knowing how to manipulate and control the camera settings will make possible to achieve all of the above-mentioned real estate photography principles and, thus, to engage deeply their clients. This entry makes a parallel between the features provided by the real camera and the one V-ray provides in 3D Studio Max.

The V-ray Physical Camera in 3D Studio Max is a powerful tool which aims to narrate a certain story through its infinite number of tools. For instance, painters use different types of compositions, colors, shapes, and forms in order to convey emotions and induce feelings. Photographers and cinematographers use compositions, point of view, exposure, and motion. These settings help the authors to create their visual language. The camera is an essential and powerful tool for all interior designers and animators which they use to visualize their projects. Taking advantage of its wide variety of settings, interior designers would be able to establish a full control of the perspective and as a consequence to enhance the quality of their final output. There are some really vital elements that need to be considered in order to obtain a better understanding of how the V-ray Physical Camera works and how its settings could be used for the needs of the interior designers.

The V-ray render engine is a complex plugin that offers an infinite number of settings enabling users enhance the realism and avoid many problems such as: noise, flickering, etc. Most of the V-ray menu options are highly dependent on each other. The researcher will explore in-depth the most important V-ray Physical Camera abilities, rather than explaining the most essential settings in a top to bottom manner. In order to establish clarity, the author's considerations are focused on the camera as an important element that has a significant contribution to the quality of the final render. Furthermore, the camera constitutes just part of a complex render algorithm which is based on the settings, provided by the main V-ray menu. This menu provides a large number of abilities that improves the rendering and its performance, such as: Global Illumination (GI), Image Sampler, Adaptive DMC, etc.

Thus, a parallel will be done between the real-world camera and the one provided by V-ray in 3D Studio Max, called V-Ray Physical Camera.

This comparison aims to identify whether the V-ray Physical Camera has the same abilities and settings that the real-world digital camera has, in order to achieve and incorporate the five principles listed above.

Many experts claim (Obeo 2017), the real-estate photography has some special requirements to the equipment, e.g., the photographers should be provided with a digital single lens reflex

camera (DSLR) body, tripod, flash, and a full gamut of lenses. V-ray in 3D Studio Max offers all of these facilities – an effective synergy between the V-ray Physical Camera, V-ray Lights, and some advance render settings. In addition, many practitioners recreate the flash effect by aligning a V-ray white-colored light with a very small amount of multiplier to the camera.

The real-world camera (DSLR or a mirrorless interchangeable lens camera) enables their users to control a number of settings, some of which are quite important for incorporating all of the above-mentioned design principles. The analysis will be based on the following control settings:

- Control the field of view
- Controlling exposure (shutter controls and aperture controls)

Field of View

The field of view is one of the most important parameters to which designers should pay attention. It illustrates what angle is captured by the lens and thus it enables the interior designers to incorporate principles: 1, 3, 6, and 7 (Lohrman 2014) in their projects:

The field of view is dependent of two main factors, explained by Douglass Kerr in his study "Equivalent Focal Length":

- The focal length – it determines the angle of view or, in other words, how much of the scene will be captured. The greater the focal length, the narrower the field of view is (Kerr 2009).
- The camera's format size – it refers to the size of the film frame or with the size of the digital sensor. In general, the smaller the format size, the smaller the field of view. Nowadays, the most popular digital single reflex cameras are manufactured with sensors nearly equal to those of 35-mm film. For example, regarding the digital photography, a lens is deemed to be a "normal lens" when its focal length is approximately equivalent to its sensor diagonal size (Kerr 2009).

In photography, there are certain types of lenses that enable photographers to capture interior scenes with different field of view. Some widely available lenses according to the standard 35-mm cameras are the following:

- Normal lens (50 mm, 85 mm). It reproduces fairly the same what the human eyes see.
- Wide-angle lens (10–42 mm). When comparing with the normal lens, it captures relatively wider angle. For instance, small-sized bathrooms, bedrooms, and cellars are difficult to shoot without having such kind of lens. Many experts and photographers claim that all real estate look better when using a wide-angle lens. The type of lens should be selected carefully in order to avoid distortion and inaccurate perspective.
- Zoom lens (100–800 mm). Nevertheless, it is rarely used for taking photos of real estate scenes – it captures relatively narrower angle, comparing with the normal lens. This lens allows the users to adjust the focus ring in order to change the focal length. This process is known as lens breathing. However, by using this lens, the photographers should be aware that they distort the depth of field (DOF).
- Depth of field – There is a plethora of terms that are tossed around DOF. However, Nagahara et al. (2008) determine the depth of field as a range of scene depths that appear focused in an image. Furthermore, the strength of DOF is highly dependable by the aperture. By successfully utilizing the DOF, the real estate photographers could emphasize certain focal point of the living space that should be in focus and visually appears as the most obvious point spotted in the interior.
- Fish-eye lens (7–16 mm) – this lens provides an immensely wide angle and it distorts the straight lines into curves. The interior photographers utilize it when it comes to creating some special effects or unconventional point of view.

A comparison between the real-world camera and the V-ray Physical Camera features, which is based on the above-mentioned characteristics, is illustrated in Table 1.

3D-Rendered Images and Their Application in the Interior Design, Table 1 Comparison between the Field of View (FOV), provided by the Real-World Camera and the V-Ray Physical Camera

Field of view	Real-world camera	V-ray Physical Camera
Depth of field	Yes	Yes (users can specify the DOF depending on the film/sensor preset chosen)
Focal length	Yes	Yes (default is 40 mm and could be customized)
The camera's format size	Yes	Yes (default is 35 mm and could be customized)
Lens breathing	Yes	Yes (default is 1.0 and could be adjusted)

Exposure Control

The most important exposure controls on your camera are the shutter speed, aperture, and ISO, because they affect the total amount of light hitting the camera sensor (Curtin 2011). These settings are also determined as an "exposure triangle," by photographer Barry O Carroll (www.bocphotography.com).

The V-ray exposure control menu (Figs. 1 and 2) allows to adjust these settings and to choose between different modes when applying the exposure control. This menu offers a number of settings which are quite essential (Table 2).

Based on this table, the comparison of the exposure control settings will be like this, illustrated in Table 3:

It is also important to note that this menu enables users to adjust the white balance – quite essential features that photographers use to remove some unrealistic colors.

The researcher illustrates below some renders produced with V-ray 3.20.03, compared with photos which are taken with real-word digital camera.

Renders

The V-ray Physical Camera productions are illustrated below.

3D-Rendered Images and Their Application in the Interior Design, Fig. 1 V-ray Physical Camera menu basic parameters. (Source: Screenshot from the interface, 3D Studio Max 2016)

In Fig. 3, there is a comparison between a photo and a V-ray-rendered image. The right part of the image is rendered with V-ray, while the left is taken by DSLR camera.

Figures 4 and 5 illustrate an interior which is rendered with V-ray Adv.3.03

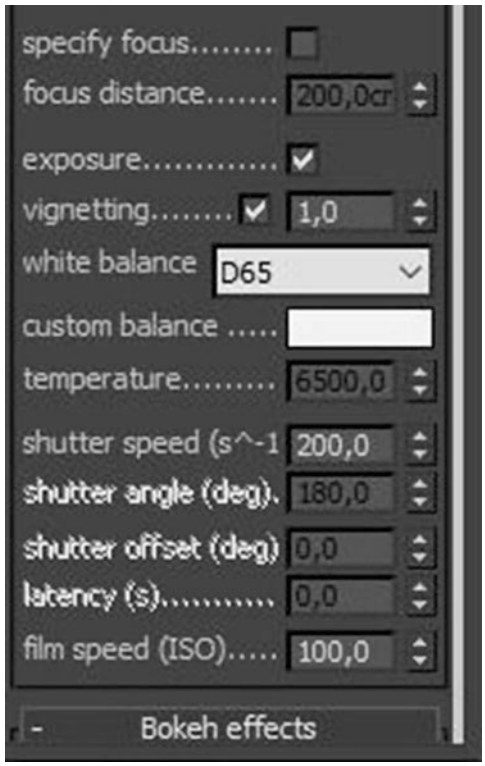
V-ray Physical Camera, ISO: 400

Shutter speed: 1/60, f 8, Vignetting – off. Lens: 50 mm.

Resolution: 6666 × 5430

The image above shows the quality of realism, produced by V-ray Physical Camera with Wide-angle lens, 28 mm and ISO 400.

All renders are produced with Vignetting: off. By enabling this setting, some dark areas appear at the image corners which could be considered from the designers as a flaw.



3D-Rendered Images and Their Application in the Interior Design, Fig. 2 V-ray Physical Camera menu (Source: Screenshot from the interface, 3D Studio Max 2016)

3D-Rendered Images and Their Application in the Interior Design, Table 2 V-ray exposure control menu

V-ray exposure control menu	
Mode	Allows to choose between different modes, e.g., photographic
Camera node	Specifies certain node from which the camera settings could be taken
Exposure value (EV)	It controls the exposure and enables to adjust the image as brighter or darker
Shutter speed	The same function as the shutter has in the digital photography. The value is illustrated on numbers, e.g. 1/200 in V-ray is 200
f-number	Controls the aperture with the same step as they are designated in the photography (1.4, 2, 2.8, 5.6, 8, 11, 16, 22)
ISO	It determines the film sensitivity. Smaller value makes the render image darker, and larger value – brighter. Unlike the digital photography, the large amount of ISO does not increase the noise in the picture

3D-Rendered Images and Their Application in the Interior Design, Table 3 Comparison between the exposure control settings provided by the Real-World Camera and the V-Ray Physical Camera

Exposure control settings	Real-world camera	V-ray Physical Camera
Shutter speed	Yes	Yes
f-number	Yes	Yes
ISO	Yes	Yes

Conclusion and Discussion

Taking into account all of the explained considerations, it is clear that CGI has a strong and essential impact on the interior designer's workflow. Today's clients have very high expectations and very short attention spans. Thus, the interior designers face a challenge to constantly improve the quality of their outcomes, by providing their consumers with top-quality projects. In order to achieve the expected results, the practitioners should optimize the time they spend to enhance their performance. Being aware of the abilities that the contemporary 3D software and its related plugins provide will significantly facilitate the relations between interior designers and their clients. The listed analysis and illustrative examples above suggest that V-ray and its camera could be successfully adopted by the professionals in order to create visually compelling, high-realistic images. V-ray Physical Camera is unable to solely achieve the desired render quality – the CGI realism is a result of complex algorithm that in general includes the accurate use of materials, lighting, camera, and some generic render settings. Nevertheless, the camera plays quite essential role when it comes to visualizing the project and the V-ray Physical Camera provides users with all abilities that the real-world camera does. However, regarding the parallel between these two elements: the virtual and the real-world one, the V-ray Physical Camera has an advantage regarding the ISO. The real-estate photographers often suffer when using

3D-Rendered Images and Their Application in the Interior Design, Fig. 3 Comparison between photo and V-ray render. (Source: Created by the author – Petyo Budakov, Ph.D. in 3D Studio Max 2016)

3D-Rendered Images and Their Application in the Interior Design, Fig. 4 Interior design, rendered with V-ray. (Source: http://help.chaosgroup.com/vray/help/rhino/200R1/images/tutorials/interior/Final%20Render%20002.png; Created by the author – Petyo Budakov, Ph.D. in 3D Studio Max 2016)

3D-Rendered Images and Their Application in the Interior Design, Fig. 5 V-ray-rendered image (Source: Created by the author – Petyo Budakov, Ph.D. in 3D Studio Max 2016)

inaccurate ISO values that make their photos noisy or grainy. This problem is completely resolved by the unique V-ray algorithm which opens new horizons to achieve extremely high realism in terms of interior design projects. Furthermore, the application of the 3D-rendered images have its strong impact on the real-estate marketing – 3D models are used to promote the sale of property by providing lenders and investors with a good understanding of the project's vision. The high-realistic 3D virtual projects significantly facilitate the sales of incomplete properties by providing buyers with a clear vision and precise idea of their future homes. Obviously, the economic benefits are also present – instead of using some less attractive two-dimensional sketches, wasting time until the property is accomplished, and then hiring a photographer to take the photos, the interior designers are capable to do all this in advance. As a consequence, the project becomes much more affordable and a recently conducted survey by Real Estate in a

Digital Age (2017), 50% of the buyers find the 3D visualizations and virtual tours as a preferable option that facilitates their final decision for purchasing.

As a conclusion, the 3D-rendered images transform not only the interior design in general but also make a strong impact on the real estate marketing.

Cross-References

- ▶ 3D Modelling Through Photogrammetry in Cultural Heritage
- ▶ 3D Visualization Interface for Temporal Analysis of Social Media

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6 DoF Interaction

- ▶ Virtual Hand Metaphor in Virtual Reality

AABB, Aligned-Axis Bounding Boxes

- ▶ Spheres, AABB, and OOBB as Bounding Volume Hierarchies

Absorption

- ▶ Videogame Engagement: Psychological Frameworks

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design

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Synonyms

Accord; Conform; Formalize

Stylization is at the heart of 2D animation design and is only recently being more fully explored in 3D animated films. In the early days of 3D animation, the push for realism in lighting, rendering, and deformations displaced a pursuit of stylization in the quest to expand the capabilities of computer graphics technology. With those technical problems solved, 3D animation has more recently embraced stylization in design and character movement. Stylization also can be interpreted by some as playfulness, and "play is at the heart of animation" (Powers 2012, p. 52). Nature can be seen as an "abstract visual phenomenon" (Beckman and Ezawa 2012, p. 101), and "the portrayal of hyperrealistic human characters in 3D animation can lead to the alienation of an audience, as they may not accept them as being real" (Kaba 2013, p. 188). It is the ability of animation to "break with naturalistic representation and visual realism" (Linsenmaier 2011, p. 1) that is observed as one of the strengths of the art. This entry discusses the implications of stylized design and its use in 3D animated films while drawing important references to traditional hand-drawn animation stylization processes that pose a challenge to modern 3D animation studios.

Definition

Stylization is the process of depicting or treating a subject in a nonrealistic approach according to an artistic convention. Stylization in animation includes the two- and three-dimensional graphic representations of characters and objects as well as the fourth dimension, stylization of timing, and movement.

Background

"Traditionally, computer graphics pursued the reproduction of real world. Consequently, many efforts were devoted to the photorealistic approach of rendering and processing images" (Sparavigna and Marazzato, p. 1). This observation is important as it identifies a fundamental challenge of stylization in 3D animated feature films. Animated films are most often driven by the concerns of narrative storytelling structure. Although some subject matter in narrative story may benefit from a photo-realistic approach to 3D imagery, the desired effect of many films is to remove the audience from their daily experience and provide immersion into visualizations that depart from realism. Sparavigna observes, "However, it is not obvious that a photorealistic processing is always to be preferred. . .Hand drawn illustrations can better explain a scene than photographic plates, because in illustrating complex phenomena, they can omit unnecessary details and propose only fundamental objects" (Sparavigna and Marazzato, p. 1). One benefit of a departure from photorealism is the ability to communicate effectively and efficiently. Visualization in narrative film structure provides an opportunity to reinforce story points, clarify what is taking place, and also enhance the emotional context of the screen experience for the audience.

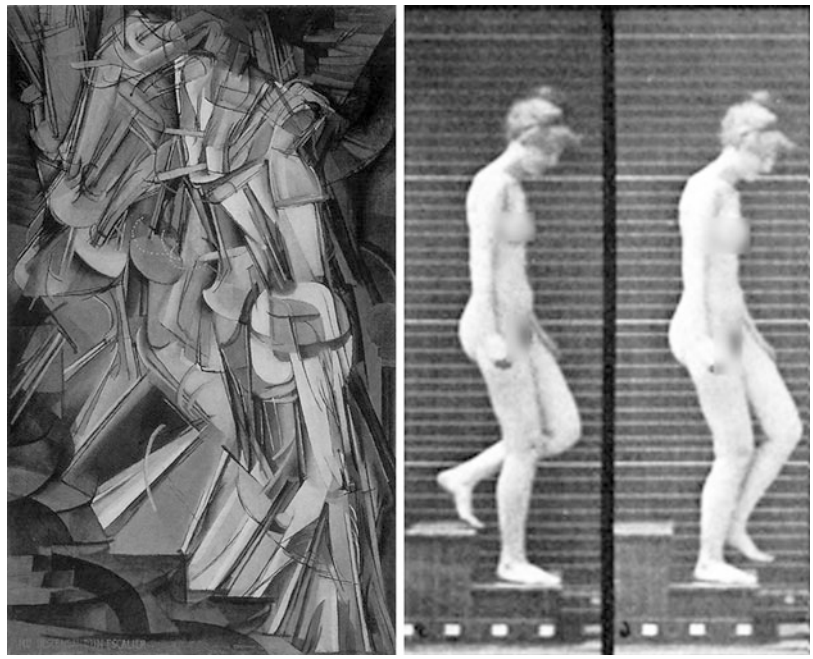
When examining the art of oil painting, where the design and construct of imagery is of equal importance, the movements of Postimpressionism and Modernism exemplify this point. The visual experience in Vincent Van Gogh's Starry Night is entirely dependent upon his unique interpretation of the observed phenomenon of the night sky. Without this process the work would lose its visual identity and much of its emotional content (Fig. 1).

In Marcel Duchamp's Nude Descending a Staircase No. 2, we observe the power of stylization in communicating motion and once again emotional context (Fig. 2).

Definition of *Style*

The *Oxford Dictionary* offers the following definition for *style*, "A distinctive appearance, typically determined by the principles according to which something is designed" (Oxford 2015). The term "distinctive" is helpful, as one benefit of stylization is a unique visual identity. The term "designed" implies the intent to implement a process leading to visual identity.

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 1 Van-Gogh's *Starry Night* to photo comparison



Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 2 Duchamp's *Nude Descending a Staircase No. 2* photo comparison

Stylization in the 2D Animation Feature Film Process

Stylization is at the heart of the animation industry. A photo-realistic design of an animal such as a bear cannot be easily registered for copyright; however, a highly stylized interpretation of a bear such as Hanna and Barbera's *Yogi Bear* is copyrightable as a creative work. Such character design copyright is at the foundation of animation merchandising. Stylized character designs are highly profitable for animation studios often generating more returns than the initial film the design appeared in.

The production process of traditional 2D animated feature films leveraged stylization at many points within the creation timeline. It was often highly stylized representations which first visualized a story idea in the *visual development* phase of preproduction. Stylization was a central part of the 2D *layout* process where line drawings for each background painting were carefully created. Following the instructions of an *art director*,

specific stylization concepts would be applied by layout artists as they would interpret the setting of the film, designing backgrounds for all shots within the film. The *supervising animators* then applied stylization, as they began the experimental animation that would set the tone for their characters' performances. The final design of the character was informed by the stylistic theme of the film. In these images from Walt Disney's 1959 feature *Sleeping Beauty*, it is evident that stylistic choices created for the background design in a shot flowed into the interpretation of line and form in the character design (Fig. 3).

The architectonic styling of the gothic-inspired backgrounds by stylist Eyvind Earle carry through into the angular interpretation of the characters; a harmony is achieved between the stylization applied to the props, set elements, and the characters.

However, the stylization process did not end with the look and feel of the character designs, backgrounds, and props. Stylization was central to movement in character animation; the animation of the characters themselves provided a richly stylized experience of real-world motion and timing, much in the same way a ballerina stylizes such mundane activities as walking or such unreal activities as flying like a swan.

Finally stylization was also applied in the interpretation of natural phenomenon. This example from Walt Disney's *Hercules* shows a stylized approach to the effect of a smoke cloud. The representation favors specific types of curvilinear treatments and angular oppositions. The visual interpretation stands in marked contrast to the same event in the physical world (Fig. 4).

Realism in Early Computer Graphics

The value of computer-generated imagery as a visual effects element for live-action film was evident from its early use such as in the 1973 film *Westworld* and the 1977 film *Star Wars Episode IV*. Throughout the 1980s computer graphics played an ever-increasing role in live-action visual effects. Animation that had traditionally been accomplished through stop-motion techniques was soon replaced by 3D computer animated effects. Accordingly, 3D animation tools evolved along a trajectory of photorealism. Lifelike portrayals of light and shadow as well as color were necessary for seamless compositing with live-action elements. The need for realistic treatments influenced the evolutionary path of 3D technology during the same period when uses for 3D graphics and animation were still being defined. After Pixar's great achievement and critical success with *Toy Story* in 1994, it was established that 3D animation could compose the entirety of a film. Rather than a means to an end, as in the case of visual effects, 3D animation had become a final product. It would take however

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 3 Design examples from Walt Disney Pictures' *Sleeping Beauty*

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 4 Walt Disney Pictures' *Hercules* to photo smoke comparison

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 5 Example of thick ink lines from early television animation (1950s)

several years to break from the pursuit of realism and implement stylization on a broad scale.

The Influence of Technology

Early Television

Early television broadcasts were of limited resolution with two alternating fields of horizontal lines creating each final frame. The thin lines of hand-inked animation cells used in theatrical shorts did not display well, and at certain tangents to the horizontal could be lost altogether during broadcast. The use of thick ink lines in television animation produced a solution that was not only functional but also a stylistic standard for the new medium (Fig. 5).

Early Internet

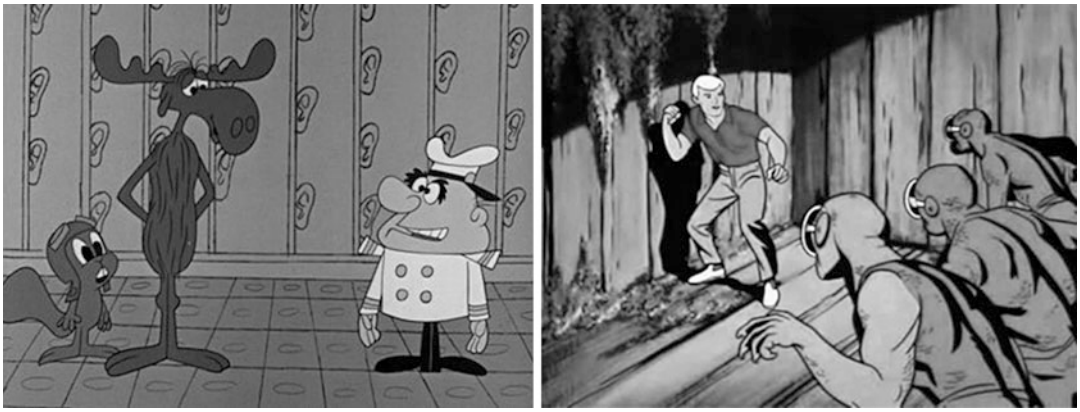
Early web animation utilized Flash software and introduced the use of stylized thick ink lines to vector animation. Flash vector animation populated the web of the 1990s offering motion graphics via the low-bandwidth Internet connection common for that time. Flash software was adapted for television production as it offered timesaving advantages previously impossible in the limited animation repertoire. The characteristic use of line and shape from early web animations found its way into many television shows of the last decade. A clear visual parallel can be seen in the flat graphic character styling favored by early television animation of the 1950s and the Flash-influenced television designs of the last 15 years (Fig. 6).

Filmmaking

Stylization and Genre

Stylizations themselves can be seen to splinter through the prism of genre. For example, the

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 6 Examples of Flash television animation styling (2000s)



Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 7 Example – genre stylistic differences in early television animation

stylistic conventions in *Rocky & Bullwinkle* contrast against the variations seen in *Johnny Quest*, which was influenced by comic book illustration (Fig. 7).

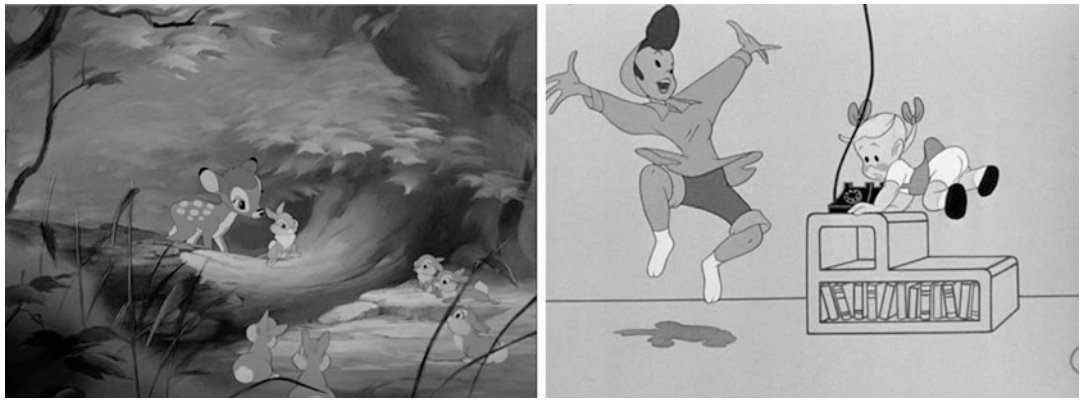
Early Disney theatrical features, such as Bambi, can be seen in stylistic contrast to musically derived works such as *Fantasia* (1940) or *Make Mine Music* (1946). In *Bambi* the soft-edged painted treatments by stylist Tyrus Wong set the mood and look of the forest in which the highly stylized design of the character Bambi, from animator Marc Davis, performed. In *Make Mine Music* minimalized character and background treatments in the segment *All the Cats Join In* were a significant departure from more detailed human characters in the narrative plot-driven features (Fig. 8).

The music-driven films were segmented into separate capsules more indicative of the animated short format. Narrative-driven features had the burden of clarifying complex character arcs, staying onscreen for extended periods. More detailed facial treatments were dictated by these genre-induced requirements (Fig. 9).

For example, the white region of the eye is important in subtle facial expressions, and a more stylized treatment of an eye may not encompass the same expressive range.

The Role of Stylization in Storytelling

Stylization plays an important role in narrative story telling as seen in such early live-action films as Murnau's 1922 *Nosferatu* where the stylized uses of shadow and form set an eerie context or in animated sequences such as the stag fight



Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 8 Background and character comparison of *Bambi* and *Make Mine Music*

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 9 Facial detail stylization – comparison of *Bambi* and *Make Mine Music*

near the end of the theatrical feature *Bambi* where the stylistic treatments of color and form enhance the emotional drama of the battle (Fig. 10).

Design Principles and Screen Composition

Stylization is born of visual design principles and gains effect from their successful implementation. The elements of visual design are the tools of the stylist as they interpret objective visual facts, into their final subjective states. *Shape*, *form*, *color*, *line, texture*, etc. are manipulated in tangible ways, employing design concepts such as *theme and variation* and *contrast* and *harmony* while enhancing rather than reducing a film's context.

Students in art programs are taught, as foundation, the importance of design principles and their corresponding emotional impact on the viewer. Often through slight changes in the alignment of forms in a visual field is *balance* achieved or such subtle linking through *contour continuation* fully realized. In their early years Walt Disney Studios was particularly sensitive to the relationship art had to animation and endured great effort and expense to expose its employees to these concepts via art classes and seminars. Transcripts from the 1930s recorded artists in such evening seminars isolating what are now taught as *animation principles* (Johnston and Thomas 1984, pp. 71–72).

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Fig. 10 Stylization examples from *Nosferatu* and *Bambi*

Trained artists filled the majority of positions in 2D animated production pipelines. The effect of this foundational integration of artists in the animation process led to the formation of visual identities within animation studios, often around a handful of celebrated stylists. Maurice Noble had a profound impact on what came widely recognizable as the "look" of a Warner Bros. animated short. Similarly Mary Blair impacted the look of Disney features and short subjects through multiple stylistic interpretations as can be seen in *Saludos Amigos* (1942), *Johnny Appleseed* (1948), and *Peter Pan* (1953), three works that demonstrate a wide range of visual interpretations.

Character Animation: Stylized Timing in 3D Features

Stylization in movement is the realm of the character animator. There have been notable achievements and a new emphasis now placed on stylization in 3D character animation.

The Emergence of Stylization in 3D Character Animation

Many efforts were made toward stylization in the early history of 3D feature film production. Some labors were rewarded more than others; however, it can be clearly seen by the time of the Pixar film *The Incredibles* (2004); the final technical hurdles had been overcome and stylization began to enter with greater impact. Not only did this film achieve significant stylization in character design but notably in character movement as well. The clarity and exaggeration of animation poses became comparable to 2D animation. A break from realism is at the center of the appeal of Mrs. Incredible whose body stretches to outrageous lengths in the hallway sequence as she tries to find her husband. A comprehensive stylistic aesthetic carried over from development art into prop design, set elements, and lighting.

Stylized character movement began to appear more consistently outside of Disney/Pixar films, as is exemplified by the Sheriff Earl character in Sony Animation Studios' film *Cloudy with a Chance of Meatballs* (2009), as the sheriff bounces and flips rather than walks through a crowd. It was clear that 3D animation directors were embracing nonliteral forms of movement. The trend continued in *Cloudy with a Chance of Meatballs II* where the fraudulent guru, Chester, twists, slides, and gyrates from pose to pose, devoid of literal movement that could have originated with motion capture technology or other automated methods. The 2010 release *Tangled* from Walt Disney Pictures stood in contrast to character movement in early 3D animation efforts as it exhibited the strong clear poses and simplified exaggerated movements that had been indicative of high-quality 2D character animation. Finally, Walt Disney Pictures' *Wreck-It Ralph* (2012) is full of stylistic motion intended to mimic the movement of pixel-graphic video games. Characters move in multiple styles within single shots. One character may be devoid of animation principles such as Arcs resulting in stiff and unnatural movement, while the next character may follow the standard principles of movement resulting in a natural screen presence. 3D character animation success stories such as these contrast with automated processes such as *motion capture*. Motion capture is a process that conceives 3D character animation as a copy of real-world movement, while keyframed 3D character animation builds on a foundation of 2D character animation traditions such as *exaggeration* or *simplification*. Automated processes negate the interpretive role of the animator as stylist, resulting in movements that are prepared rather than designed.

The Influence of 2D Animators on the 3D Pipeline

These 3D stylistic trends can be associated with the arrival of many traditional 2D animation artists who have joined the ranks of 3D studios. Many animation artists were displaced by the closure of 2D feature animation production at Disney Studios in 2005 (Forum.rottentomatoes.com 2005), as well as DreamWorks and Warner Bros. The resulting talent migrations had an impact on several 3D animated feature productions.

In the case of *The Incredibles*, it was the first full 3D feature animation effort for director Brad Bird who had been brought to Pixar by John Lasseter. *The Incredibles* production saw the arrival of animation director Tony Fucile who had been a supervising animator on the 2D film *The Lion King* before working as animation supervisor under Brad Bird on the mixed 2D-3D features at Warner Bros. In the case of *Cloudy with a Chance of Meatballs*, Sony Pictures had been on a course of introducing 2D talent within their 3D ranks as Roger Allers and Jill Culton, codirectors for *Open Season* (2006), and Chris Buck and Ash Brannon, codirectors for *Surf's Up* (2007), all had their roots in 2D feature animation. Finally codirectors Jim Reardon and Rich Moore *(Wreck-It Ralph, 2012)* were graduates of the Character Animation Department at CalArts and also had their roots in 2D animation techniques.

Challenges in the 3D Feature Film Pipeline

There is no one-size-fits-all approach to stylization nor should there be in the quest for visual identity among the scores of animated features released each year. Although stylization is widely addressed in 3D animated features today, often it is not fully realized particularly in scene design and screen composition, leaving many 3D features with a similar look, lacking visual appeal.

Stylization is a key ingredient in film, affecting qualitatively the dialog with the audience and enhancing the narrative. It should be fully implemented in animated film, where it is most readily available. It is unfortunate to see many 3D animated feature films offer little stylization and routinely forgo the advantages that stylization brings. This phenomenon can be examined from several perspectives, but here it is seen through a close look at the 3D pipeline and the hundreds of workers that create the final films.

Compartmentalization: Disintegration of the Design Process

As was explored earlier the 2D animated feature film pipeline relegated the bulk of stylistic control to relatively few artists. All of it was found in preproduction or early in the production phase of the film. The art director and key development artists along with supervising animators and the layout department determined the bulk of stylistic integration before the majority of the people involved in production would begin their work. In their early and concentrated efforts, most consequential decisions were made determining the final use of color, form, and directionality in screen composition.

However, the 3D pipeline presents a more complex and compartmentalized process. Although most 3D feature films have the benefit of both development artists and art directors, the difficulty is in the component processes collectively resulting in the final color and composition of each shot. The work of the 3D development artist gives way to the modeling artist who first visualizes the characters, props, and set elements in 3D geometry. The texture artist further contributes in ways that directly impact stylization. The composition of the scene falls to a set decorator or shot composer then continues on to layout artists who block in the camera movement affecting each scene's composition. The animator follows with the keyframing of character elements, working primarily in the roughhewn visual context of low-polygon models. In a subsequent step further animation is added through automated simulations and dynamic options and processes. Final lighting is then applied to the scene, only beginning to address the integral role of shadow and light in screen composition, at a very late stage in the process. It is when each frame is finally rendered that the shot design and composition arrive at their final state.

Implementation of stylization in the 3D pipeline involves many departments, beginning early in preproduction and ending with final render. By comparison the 2D stylization process was in the hands of few artists, heavily weighted toward the preproduction phase of the film process. The length and complexity of the production of the 3D imagery as it moves from concept to completion poses many challenges to stylization in 3D film. Even with the efforts of a dedicated production stylist, visual influence is diluted as stage by stage a single shot is completed over a long period of time.

Demographics of the Production Team

The evolution of computer-generated technology was so strenuously focused on photo-realistic achievement for such a long period that stylization developed little momentum, often weakly integrated or entirely absent. As 3D animated features quickly supplanted the 2D animated format, the balance of production personnel changed in a dramatic way. In the typical 2D animated feature film, more than 80 % of the preproduction and production team came from an art background. The 2D production team required 300–500 people most of whom had to be able to paint or draw well. As a result most crewmembers had attended art programs within universities or colleges before contributing to the film. By contrast 3D animated films require a more diverse range of skills. Computer technology is central to all the elements in each shot of a 3D film. As a result technologists are as numerous as artists on many 3D features. While a 3D character animator will graduate from an art program, a character technical director will graduate from a computer science background. The table below clarifies the proportional difference between the two respective production teams. The example compares individuals listed in both the *visual effects* and *animation* categories in the film credits for *Inside Out* (2015), the 3D example, and *The Little Mermaid* (1989), the 2D example (Table 1). The crew totals for each film are much higher; the sample was limited to the personnel involved in the production process for the two listed categories. It should be understood that the 43 people in the technical processes for 2D animation would have contributed most of their efforts in postproduction after the hands of the 307 artists have already touched the film.

The 3D film process is challenged by this change in balance, as the production team moves away from a common background in art to one pulling heavily toward digital technology. Thus,

Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design, Table 1 Demographic shift in the constituency of feature animation production units (Data retrieved from IMDB.com)

Inside Out (2015a) *3D animation*	**The Little Mermaid** (2015b) *2D animation*
Animator or character designer: **25**	Animator, painter, character design, layout, 2D effects: **307**
Software, simulation or technical: **17**	Xerographic or technical: **43**
Percentage of sample that are artists: 59 %	**Percentage of sample that are artists: 87 %**

the largely artistic process of stylization has not only been spread across a much broader span of production time but among a different set of contributors. Without a common artistic background rooted in design principles and aesthetics, the understanding of stylization and what constitutes successful implementation may be a point of conflict within 3D production teams.

Conclusion

The Need for Visual Identity

Animated feature films are more abundant today than at any other time in the history of film. The vast majority of these films are 3D animated features.

Restructuring the 3D Pipeline

It may be advisable to revisit the 3D pipeline in an effort to identify alternate methods for gaining the control necessary for significant and successful stylization. There must be an effort to simplify the pipeline or further empower the art director over component parts of the process. It may be that one art director alone will not be able to track the myriad simultaneous decisions, which are the standard for efficient 3D production. Perhaps there will be room to experiment with the art director as a team or creative unit rather than a sole individual. This team could be as many as 20 or more persons; thereby, an art director for the team would be able to monitor each shot through every stage of the pipeline.

It is further advisable that other methods such as the stop-motion animation pipeline be examined as possible influences for change. Perhaps one day final lighting and texturing will precede character animation in much the same way shaded layout drawings set the stage before the 2D animator ever set pencil to paper. As many times as the 3D pipeline is repeated, it ought to be reimagined; such a young set of processes should be ripe with experimentation. These experiments should be guided by design principles and stylization ideals, which ultimately trump technology as a film seeks its emotional connection with the audience.

Education and Training

It would be equally advisable to educate 3D production teams in artistic processes in an aggressive and meaningful way, with a desire to learn how such processes were employed in 2D animation units. Educating the team and developing a common core design philosophy would help assure that stylization goals are met at all stages of production.

It is very hopeful that stylization will be fully realized in the future of 3D animated films, as the existing tools and processes are capable of far greater results in this quest.

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Abzû

▶ Educational Game Abzû and the Lens of Fun Learning

Academic and Video Game Industry "Divide"

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Synonyms

Divide; Gap; Rigor-relevance debate

Definition

The "divide" can be classified as the limited transference and dissemination of knowledge, and the lack of collaborative projects between academics and their industrial counterparts. The extent to which the divide exists between the games industry and academia lacks clarity and needs continued research.

Introduction

Contemporary game design and development has been impaired by poor communication between related practitioners and academics (Passarelli et al. 2018; Greenwood et al. 2021). In academia, game design is contextualized within the study of games, the act of playing them, and the cultures surrounding them (Engström 2020). In contrast, at the industry level, the focus on game design has revolved around self-expression, overcoming challenges, player experiences, and making a profit (Davis and Lang 2012). The reasons for poor communication between both parties are complex, focusing on the importance of creativity and business management, and therefore attention is mostly given to game mechanics, aesthetics, and marketing strategies (Marchand and Hennig-Thurau 2013). These differences in priorities and resulting mismatch of understanding are known as the "academic-industry divide" (Colusso et al. 2017).

To further understand the *divide*, it must be understood clearly that academics and practitioners have differing motivations driving how they approach the gaming discipline. Typically, academics focus their research on how games generate social and cultural meanings, and how game mechanics and aesthetics can inform the development of new games (Engström 2020). Whereas industry practitioners focus their attention on providing immersive experiences for players and ensuring a profitable outcome for themselves (Davis and Lang 2012). A result of these differing motivations is that academics and industry practitioners often think that they are discussing the intricacies of the same situation/s, when in fact they are not, due to not understanding the importance and links between their related work.

How the Divide Is Appearing Within the Gaming Industry

Beginning in 2016, the European Commission–funded project, *Gaming Horizons* (www.gaminghorizons.eu), investigated video games

and society from a social sciences perspective (Passarelli et al. 2018, 2020). This study found that there was a clear working divide between gaming practitioners and academics. Extending on Passarelli and colleagues, Engström (2020) suggested that the divide needs to be viewed from different perspectives before a proper assessment can be made about the extent to which it exists between the games industry and academia.

Viewpoints on the Divide

There are two opposing viewpoints concerning the general academic-industry divide: the proponents for bridging the divide and those who believe that it should not be bridged.

The divide should be bridged: The ideal is that by working with industry, academics can engage in joint sensemaking to generate new and useful knowledge that can be used to improve processes and products (Shani and Coghlan 2014).

The divide should not be bridged: Based on Luhmann's (1995) system theory which outlines the extreme difficulty in integrating knowledge that has been generated in different contexts of science and practice (Kieser and Leiner 2012).

Benefits of Bridging the Divide

Within differing disciplines, studies into bridging the academic-industry divide have identified more barriers than benefits. This could be because those studies were limited to identifying barriers of the divide or were more focused on why the divide exists and not on the outcomes of successful bridging attempts (Beck and Ekbia 2018). The benefits for bridging the divide can be summed up as follows:

The benefits for academics: access to current industry knowledge, data, and practices; employment for graduates; and opportunities to innovate and to access alternative funding streams from governments or industry bodies.

The benefits for industry: access to additional avenues to solve problems; access to skilled employees; and opportunities to work on alternative projects of commercial value and access to recognized world experts within defined areas.

Barriers of the Divide

On the contrary, previous research into the divide within other disciplines has identified many barriers. These barriers of the division are categorized into three main groups: communication, knowledge transfer, and collaboration outlined below:

Communication barriers: The accessibility of research outside of academia and industry's ability to access and understand it.

Knowledge transfer barriers: Relevance issues and academics viewed as being poor at communicating their projects outside of the academic field.

Collaboration barriers: Funding and management issues; issues over project intellectual property, and perceived trust issues between the two communities.

Suggestions on How to Bridge the Divide

To assist with bridging the divide, suggestions have been offered. The suggestions have been categorized into three main groups: general, collaboration enhancement, and knowledge transference outlined below:

General suggestions: Such as the development of different documents for different audiences and using the agile research network approach.

Collaboration enhancement suggestions: Such as academics need to learn about industry practices and industry needs to learn about what academics are doing.

Knowledge transference suggestions: Such as academics developing libraries and translational resources and the development of an online space to communicate.

It must be highlighted that most of the suggestions made to reduce the divide have not been

implemented into practice or if they have, they have not been as successful as one would hope (Norman 2010).

Communities of Practice

Research that studies communities of practice have also shown that academia and industry have different core goals, views, and agendas (Gray et al. 2014; Wallin et al. 2014; Colusso et al. 2017). This has led researchers to show them as two different sets of communities. For example, academia's goal is to seek and generate knowledge and to provide training for future careers, whereas industry is focused on building products and the selling of goods to make a profit (Lameman et al. 2010; Wallin et al. 2014). The question now is whether the two communities can interact without support, or if it is better to develop an ecosystem that supports communication between the two communities.

At the 2021 Interactive Games and Entertainment Association (IGEA) Education Summit, a panel discussed the forming of a community of practice within the Australian and New Zealand population. The panel also attempted to prompt the values of academics and practitioners working together to improve the education of future members of the game development community, which is a good starting point for future discussions (IGEA 2021).

With this knowledge will Australian and New Zealand universities and video game practitioners take up the torch that the IGEA are proposing, to start forming collaborations such as developing programs like the Mighty Kingdom Graduate Program (IGEA 2021) or the Dc Labs Institute (Ingram et al. 2020). Only time will tell where this revolution will lead.

Cross-References

- ▶ Computer Graphics, Video Games, and Gamification Impacting (Re)habilitation, Healthcare, and Inclusive Well-Being
- ▶ Gamification and Serious Games
- ▶ Gamification of Modern Society: Digital Media's Influence on Current Social Practices
- ▶ Serious Online Games for Engaged Learning Through Flow

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Acceptance Gap

▶ Uncanny Valley in Virtual Reality

Accessibility

▶ Accessibility of Virtual Reality for Persons with Disabilities
▶ Audio and Facial Recognition CAPTCHAs for Visually Impaired Users
▶ Making Virtual Reality (VR) Accessible for People with Disabilities
▶ Unified Modeling Language (UML) for Sight Loss

Accessibility in Games

▶ Video Games and Accessibility: A Case Study of The Last of Us II

Accessibility of Virtual Reality for Persons with Disabilities

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Synonyms

Accessibility; Games; Rehabilitation; Virtual reality

Definition

Immersive virtual reality – i.e., completely blocking out the real world through a virtual reality display – is not currently universally usable or accessible to many persons with disabilities, such as persons with balance impairments.

Introduction

Virtual reality (VR) has traditionally been too expensive for the consumer market, which has constrained its applicability to high cost applications, such as soldier training, surgical training, and psychological therapy. However, with the decreasing costs of head mounted displays (HMD) and real-time tracking hardware, VR may soon be in homes all over the world. For example, HMDs such as the Oculus Rift (https://www.oculus.com/) for VR and Microsoft's upcoming Hololens (https://www.microsoft.com/microsoft-hololens/) for augmented reality (AR) will change the way that users play games and experience the surrounding real world, respectively. Moreover, VR and AR can now be effectively enabled through smartphones at an even lower cost with the simple addition of a head mounted case, such as MergeVR's headset (http://www.mergevr.com/). That is, everyone with a smartphone has virtual environment (VE) devices in their pockets right now. Thus, VR will be available to consumers who may

have disabilities. However, there is minimal research that highlights the special needs of these diverse populations with respect to immersive VR. Thus, there is a significant amount of research that must be conducted to make VR accessible to persons with disabilities. This entry reviews the recent efforts of the San Antonio Virtual Environments (SAVE) lab to better understand how persons with disabilities are affected by VR accessibility.

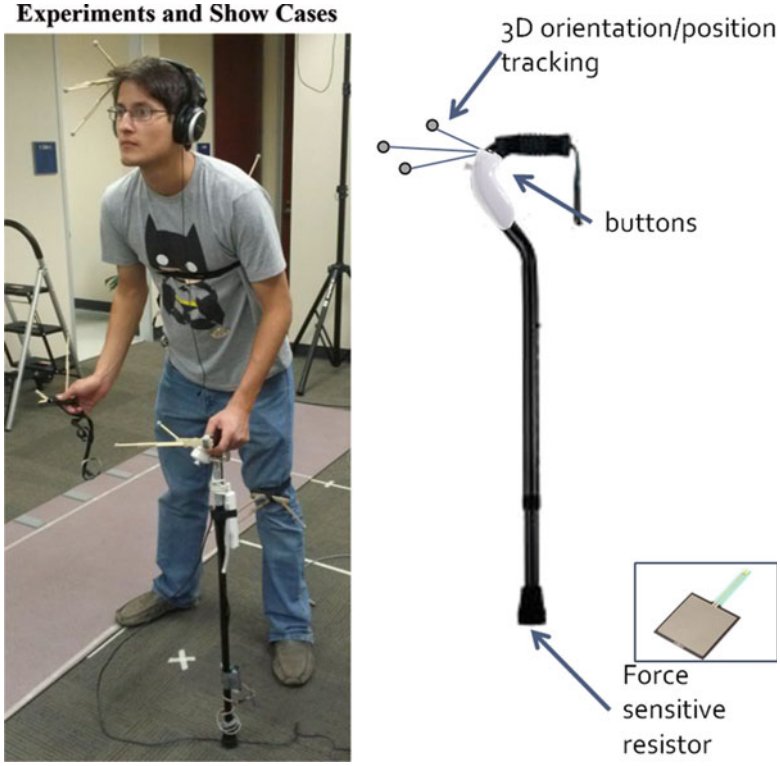
Background

Most of the information that is known about the accessibility of VR for persons with disabilities comes from research on virtual rehabilitation. VR has been shown to have significant benefits to rehabilitation. A VE is not subject to the dangers and limitations of the real world (Boian et al. 2002; Burdea 2003; Wood et al. 2003; Merians et al. 2006), which expands the types of exercises that patients can practice, while still having fun in the case of VR games. In general, research suggests that VR and VR games have measurable benefits for rehabilitation effectiveness (Sveistrup 2004; Eng et al. 2007; Ma et al. 2007; Crosbie et al. 2008; Adamovich et al. 2009) and motivation (Betker et al. 2007; Verdonck and Ryan 2008).

Visual Feedback: Visual feedback is any kind of feedback for rehabilitation delivered to the patient through the visual modality. This includes mirrors, computer displays, and VR. Visual feedback has been shown to be effective in rehabilitation (Sütbeyaz et al. 2007; Čakrt et al. 2010; Thikey et al. 2011).

Gait Rehabilitation: Gait (i.e., walking patterns) rehabilitation is the main type of rehabilitation that requires navigation in a VE. Most systems used a head mounted display (HMD) or a large LCD screen. Results with VR systems in gait rehabilitation were positive (Fung et al. 2006; Tierney et al. 2007; Bardack et al. 2010).

Design Guidelines for VR Rehabilitation Games: There has been much research on deriving



Accessibility of Virtual Reality for Persons with Disabilities, Fig. 1 Game Cane. The user leans forward to move the character forward and rotate the cane to steer. If more weight is put on the cane (as measured by the force sensitive resistor), it will disrupt the movement of the character in the game

design guidelines for VR rehabilitation games based on results of empirical studies (Flynn et al. 2008). Alankus et al.'s guidelines include: simple games should support multiple methods of user input, calibrate through example motions, ensure that users' motions cover their full range, detect compensatory motion, and let therapists determine difficulty (Alankus et al. 2010). There have been many other guidelines derived (Goude et al. 2007; Broeren et al. 2008; Burke et al. 2009a, b) and there is a need for more focused game design research and development for specific populations (Flores et al. 2008).

SAVE Lab's Research in Immersive VR Accessibility

Making Balance Games More Accessible

Many existing balance based games are not accessible for many persons with balance impairments. To address this issue Cantu et al. developed a novel interface – Game Cane (Fig. 1) (Cantu et al. 2014). Game Cane enables the user to control games and play balance based games using the natural affordances of a cane. The Game Cane project has two goals: (1) make balance games more accessible and (2) help users with balance impairments to improve their balance.

Specifically, users control orientation through rotating the cane and leaning in each direction to control direction of movement. To meet the rehabilitation goal of reducing dependency on the cane, putting weight on the cane will disrupt movement (e.g., make a character run slower; make a car more difficult to turn).

Results of a user study suggest that the Game Cane is easy to use and serves as sufficient motivation to depend less on the cane during game play. In the future, we plan to study long term effects of balance improvement using Game Cane.

Latency

One of the major potential threats to accessibility is latency. Latency is the time it takes between a user moving and the movement being shown on a virtual reality display (e.g., a head mounted display, a 3D projector). All VR systems have latency in them and classically latency has been the enemy of VR, often significantly hindering user performance.

However, we hypothesized that in some cases, extra latency can potentially be used for the user's benefit in areas such as stroke rehabilitation. For example, in a recent study (Samaraweera et al. 2015), we intentionally applied an extra 200 ms of latency to the user's virtual body, but only half of the body, which made the unaffected half of the user's body try to compensate for the latent half. In this study, participants were asked to walk towards a virtual mirror in which they could see their avatar (Fig. 2). Interestingly, participants did not perceive the latency effect. Based on her

Accessibility of Virtual Reality for Persons with Disabilities, Fig. 2 Benefits of Latency: a look into a virtual mirror where the avatar has 200 ms latency applied to one side of the body

promising results, we are now conducting a study on the benefits of this one-sided latency for stroke patients who commonly have increased weakness on one side. The ultimate goal is to apply her technique to help rehabilitate asymmetric walking patterns in these patients.

Accessibility for Children with Autism

Motivation may be a factor in the accessibility of 3D User Interfaces for children with Autism. It has been shown that many children with Autism have very specific and individualized interests, many of which may be uncommon. To more effectively motivate children with Autism to practice hand-eye coordination tasks, we created a virtual soccer game, Imagination Soccer (Fig. 3), where the user played the role of a goalie and he/she could customize a virtual human kicker (Mei et al. 2015). We compared customizable versus noncustomizable virtual humans. As expected, we found that the participants preferred the customizable virtual humans. Surprisingly, the users also exhibited significantly improved task performance with the customizable virtual humans. This suggests that customization is a plausible way to make interfaces more accessible for children with Autism.

Raising Awareness About Persons with Disabilities

Virtual reality still has a long way to go before it can be considered accessible for persons with disabilities. To educate future VR designers and engineers about accessibility in VR, it is important to raise awareness about the needs of persons with disabilities. One of the ways that the SAVE lab has been raising awareness is through our Virtual Reality Walk MS (SAVELab 2015b) (Fig. 4) and our Virtual Reality Walk for Autism (SAVELab 2015a). Using Unity3D (unity3d.com) and Exitgames Photon (exitgames.com) for networking, the VR walks mimic the real fundraising walks that occur annually, effectively involving potential participants who may not be able to attend the real walk. The VR walks are run concurrently with the real walks. Users can choose an avatar and virtually walk around a virtual AT&T center. Users who are remote are also able to communicate with people at the real walk since the software runs on mobile phones. However, there are still many research problems to be solved to make communication more natural and the interface more transparent. This is an area where new advances in augmented reality technology may help to address these issues.

Accessibility of Virtual Reality for Persons with Disabilities, Fig. 3 Imagination Soccer – a game for training hand-eye coordination for children with Autism

Accessibility of Virtual Reality for Persons with Disabilities, Fig. 4 Virtual Reality Walk MS – a mobile, multiplayer virtual environment for raising awareness about multiple sclerosis

Conclusion

The SAVE lab is trying to push the boundaries of VR to make it accessible for all users, including persons with disabilities. We have conducted fundamental research towards understanding how persons with disabilities interact with VR and have identified techniques to make VR more accessible. However, there is still a significant amount of research to be done before immersive VR can truly be accessible to everyone.

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A

Accessible Game Development

▶ Visual Accessibility in Computer Games

Accommodation & Convergence

▶ Spatial Perception in Virtual Environments

Accord

▶ Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design

ACI

▶ Engaging Dogs with Computer Screens: Animal-Computer Interaction

Action Adventure Game

▶ Disney Toontown Online, a Massively Multiplayer Online Role-Playing Game
▶ Fantasy XVI Online, a Massively Multiplayer Online Role-Playing Game
▶ God of War (2018), an Action-Adventure Game
▶ The Elder Scrolls V Skyrim

Action Role-Playing Game

▶ Dark Souls III, an Analysis
▶ Kingdom Hearts (2002): An Analysis

Action RPG

▶ Dark Souls RPG Through the Lens of Challenge

Action-Adventure

▶ God of War, an Analysis

Action-Adventure Game

▶ Assassin's Creed, an Analysis
▶ Legend of Zelda Breath of the Wild and the Lens of Curiosity

Active Learning

▶ Games and Active Aging

Active Videogames

▶ Games and Active Aging

Activist Games

▶ Political Game Design

Adaptation

▶ Redesigning Games for New Interfaces and Platforms

Adaptive Music

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Synonyms

Algorithmic composition; Dynamic music; Generative music; Interactive music; Nonlinear music composition; Organic music; Procedural music; Video game music middleware

Definition

Adaptive Music refers to a computer entertainment system for dynamically composing a music soundtrack in response to dynamic and unpredictable actions and events happening in a video game. Since its inception, the concept has evolved into a general approach to composition that takes into account the possibility of changing the musical material during gameplay, sometimes termed "composing for opportunities." The underlying principle is that music in a game could be initiated, triggered, mixed, or completely generated by directing the system in a way that is aesthetically appropriate and natural to the game and the user's actions. The common architecture of such a system comprises a database of musical segments or clips containing one or more musical sequences that could be launched in response to the game logic and looped as long as the scene is playing. Additional clips could be added or mixed or subtracted/muted to change the overall contents of the music. Special treatment is done to enable smooth transitions between clips, as well as adding short musical or sound elements, often called stingers, that might be triggered in response to user actions or facilitated switching music in the case of transitions by inserting music for ending or starting a musical segment. In some cases, musical algorithms can be deployed to generate the music materials directly by sending note or

musical playing instructions to a synthesis engine. Technically this requires to have a synthesizer or virtual music instrument available in the game engine to produce the sounds, which is in addition to the more common use of an adaptive playback and mixer of prerecorded music segments stored as audio files.

Adaptive Composition Methods

The main two common methods for adaptive music are horizontal resequencing and vertical layering or remixing (Sweet 2014). The names imply operations performed by a game sound system on pre-recorded musical materials that are arranged in a traditional multitrack view, where time is represented horizontally, and the different musical tracks are lined up horizontally. According to such arrangement, each vertical juxtaposition of musical tracks corresponds to a valid musical combination of simultaneous music materials, often arranged according to the different musical instruments performing the music.

The adaptive operations correspond to skipping forward or backward in time and muting or changing the relative volume/balance of musical playback between tracks. Since in practice the skips cannot be done between random time-points in a track, the music is segmented or arranged ahead of time into fixed clips that can be repeated or looped, or can be smoothly switched to different clips, with transitions happening only between ending and starting points of the clips. Accordingly, in some modern software, the geometrical arrangement of musical data is flipped so that the different clips are stacked vertically, with each horizontal arrangement corresponding to a specific scene or level in the game, with tracks containing concurrent clips arranged horizontally. Such grid/spreadsheet-like data arrangement creates a correspondence between game scenes or game levels and the musical data arrangement, where changes in game scenes or levels correspond to moving up or down on the musical data grid.

Special treatment is given to transitions, where switching between clips is done on the musical beat, so that the rhythmical structure of the music will not be interrupted. In cases where such matching is not possible, other transition methods are used, such as inserting fixed music segments that either create an ending of the previous music and starting of new materials, or create a gradual change, such as speeding or slowing down to match the tempo difference from the source (current) to the target (next) clip. Since such transition clips are not played in a loop, they are often treated as stingers, or singularly triggered musical events. Methods for automatically determining valid transitions between points in pre-recorded music requires analysis of the audio for repetitions by extraction of musical features. Research on automatic transitions detection is discussed in the algorithmic composition section.

Music Versus Sound Effects

A distinction between music and sound effects was traditionally evident as music would be produced by musical instruments and composed in some well-established musical style. Sound effects or so-called Foley effects, named after Jack Foley, were designed to create sounds that correspond to physical events that are nonmusical in their nature and largely correspond to sounds made by objects present in the game. Since the sound engines already in the early game consoles allowed both synthesis of simple tones and playback of short recordings, the same system was used to trigger sound effects and music. Historically, the earliest sounds in pinball machines were produced by physical devices, such as solenoids hitting bells, which could be all classified as sound effects. Music playback was often made available in the early game arcades, but mostly in order to register the games as jukeboxes rather than gambling machines that were illegal (Beep 2016). As the availability of both music generation and playback of sound effects was historically present in sound games, the combination of both types of sounds became part of the sound palette available to music game composers, blending composition and sound design into one common compositional strategy. In

parallel, experimental musical practices that were unrelated to video games have been explored, since the end of nineteenth and beginning of twentieth century, the possibilities for including nonmusical sounds in musical compositions. With experimental musical genres moving to mainstream in classical and pop music, game composers today blend traditional instruments with sound effect as part of their video game music and soundtrack design.

Music Role in Video Game

A common distinction is between Diegetic and Non-Diegetic Music, a term common in film music as well. Diegetic audio refers to sound that originates in the game events themselves, which could be either sound effects related to physical events happening in the game, or music that originates from a game scene, such as musical band or radio present in the scene. Non-Diegetic or extra-diegetic music refers to composed music that accompanies the scene, usually to establish atmosphere or identify a character or situation. A simple criterion to distinguish between Diegetic and Non-Diegetic Music is whether a character in the game would have heard that music or sound. Another technical difference between Diegetic and Non-Diegetic music is that the first one is usually localized and treated in the game using 3D audio engine, while Non-Diegetic music is rendered stereo, also called 2D audio. Among the roles of Non-Diegetic music, aspects of emotional subtext, intensifying the game narrative, informing about progress or level of gameplay, are often mentioned. Both Diegetic and Non-Diegetic music are important for providing a sense of immersion in the game.

Logic of Music Triggering and Combinations

One of the distinctive features in Adaptive Music is that the arrangement of musical material has to provide multiple alternative combinations of musical materials rather than creating a single timeline of musical events. Accordingly, the term nonlinear composition is often used to describe the branching structure of musical materials in contrast to a traditional single sequential arrangement of a linear musical form. This creates a novel approach to planning a composition by creating a database of sounds and identifying one or more musical sequences to have one or more decision points. The decision points within the database then comprise a composing decision tree, with the decision points marking places where branches in the performance of the musical sequences may occur. A sound driver interprets each decision point within musical sequences depending on the unpredicted actions and events initiated by a directing system that is linked to events in the game. The directing system may also query the state of the sound driver to adjust the branching decisions, such as preventing too many loops of playing the same musical material if the game activities do not progress at sufficient pace, or initiating some branching or transitions randomly, unrelated to the actions of the game, in order to create more variety in the music. Other direct commands may be initiated by the directing system for controlling the performance of the sound driver or playback device, such as adding or removing (mixing) multiple simultaneous sounds synchronously or asynchronously with another playing clip. The synchronous versus asynchronous combination is designated according to delaying playback of new sounds in order to match the rhythmic or beat structure between musical materials or triggering the new sound at will, respectively, as well as including additional decisions about the fade settings, pickup or count-in beats, or criteria for selection of the target sounds. The design of the branching logic allows for both horizontal resequencing and vertical layering composition techniques to be implemented by creating a hierarchical or coarse-to-fine tree structure with main branches corresponding to transitions between collections of sounds arranged into themes, and fine grained decisions for track selection and combination

controlled by game levels within a theme. The details of logic handling are different across different systems. For example, in the Elias adaptive music system requests to change level, use an action preset, play a stinger, etc., react differently for each track according to their own rules, such as if a string melody track is playing a long phrase, it might wait to change after that line is complete according to a rule set by the composer, while the percussion track might be allowed to change right away. Elias has a small AI that listens for "better" places to change, such as if the rule for the Trumpet track is to change on bar 5 beat 1 and the musician is slightly ahead of the beat, the system will adapt to that change point automatically.

MIDI and Audio

MIDI and Audio are the two most common representation formats of music that are handled by sound engines. The distinction is often important for sound engines as the type of adaptive operations that are possible in each representation are very different. In pre-recorded music referred as Audio, the adaptive operations are based on playback and mixing of musical clips. In MIDI (Musical Instrument Digital Interface) that sound is generated by sending performance instruction to an electronic synthesizer. The operation possible using MIDI includes control of individual notes and instruments, thus allowing change in the instruments that perform the music, as well as adding or removing notes using algorithmic methods. Historically, adaptive operations such as change in tempo or shifting the pitch of music were reserved to MIDI, but developments in audio signal processing allow today to change the speed of playback or change the pitch of an audio recording without changing the speed of playback with minimal audible artifacts. Other music formats, such as mod files that are used in music engines known as musical trackers, are also common in video games music. Mod files combine some of the aspects of recorded clips and note triggering instructions.

Algorithmic Composition Methods

An alternative or complementary method to horizontal resequencing and vertical layering that operates on pre-recorded materials, are so-called algorithmic methods that use computer code to generate music procedurally (Collins 2009; Duarte 2020). A possible distinction between algorithmic and generative methods is that algorithms often refer to rule based, largely deterministic operations that encode musical knowledge using formal grammars or other heuristic methods, while generative methods often refer to random generation or stochastic processes. Between the two extremes, many algorithmic composition methods combine both randomness and rules to create musical materials. Some examples of such combined methods are Markov models that may be constrained or learned from examples based on some underlying musical model, stochastic grammars, Augmented Transition Networks and Petri-nets, or abstract mathematical processes such as genetic algorithms, L-systems, and artificial life. One important aspect in using any type of procedural musical generation is the mapping of computational operations to musical parameters. Separate processes might be used to model rhythm versus note or pitch structures.

More recently Neural networks have become a focus of intensive research in music generation, where musical rules are learned implicitly from large enough corpuses of examples. Common methods for such learning and generation are recurrent neural networks (RNN), or combination of RNNs with variational models such as Variational AutoEncodersx1 (VAE), Generative Adversarial Networks (GAN), and more recently Transformers (Briot et al. 2019). These methods operate mostly in the symbolic domain. Automatic remixing of audio files can be done by applying string matching methods to sequences of features extracted from the acoustic signal. One common method is using a Factor Oracle algorithm to create an automaton structure according to suffix links connecting similar subsequences in the feature representation (Assayag and Dubnov

2004). Horizontal remixing is done by skipping the audio playback according to the suffix links that assures that the transitions are sounding smooth since they share common history. This method is operating according to a principle similar to a Markov model, except that the conditioning on the past can be of different length. Due to this property the audio remixing models are also known as Variable Memory Markov Models or Variable Markov Oracle (VMO) (Wang et al. 2017).

Middleware Software

Audio and Music Middleware are software tools, often developed by third parties that are not related to the game engine software, whose purpose is to help game composers and sound designers to create and integrate audio into the game. Most modern game engines, such as Unity or Unreal Engine, provision basic audio operations that allow direct integration into the game by direct calls to playback and mixing operations. The difficulty with working directly with game development software is that the compositional process is very different from the usual Digital Audio Workstation (DAW) software that is used for composing or producing music for non-game applications. Accordingly, one of the main advantages of Middleware is providing a more natural composition interface and easy work method for composers. Other more technical advantages of using Middleware are easy integration into major game engines without dependency on game programmers, high-quality audio with control of the audio footprint and support for various compression formats, integrated sound effect and support of audio plug-ins, multithreaded platform specific optimization, and so on. Some of the major names in the industry include FMOD, Wise-Audiokinetic, Tazman-Audio Fabric, Elias Software, and Criware (Nogueira 2019). In terms of adaptive music tools, some of the substantial differences between the different middleware are their level of support for MIDI and sound design implementation.

Historical Developments

Interactive sound in video games existed since Pong in 1972, mostly to emulate sounds of pinball machines in arcade games. Generative music in video games was introduced in Ballbazer in 1984 for producing music segments between games and menu (Plut and Pasquier 2020). The music was generated by a combination of short musical riffs for melody, bass, chords, and drums, with rules for choosing the next riff, the speed, and volume of music. The first fully interactive music system iMuse was developed and used in the game Monkey Island 2 in 1991 (Land and McConnel 1994). The system is based on symbolic music representation and implements a branching structure of adaptive music composition, where the decisions on which music to play and what transitions to make are based on the game situations and designed transitions between the scenes. DirectMusic by Microsoft is a low-level API that supports composition and playback of dynamic musical soundtracks based on stored compositional material. The system was first introduced in 1996 as part of the a DirectX library, and became part of Windows 98 Second Edition in February 1999, but was deprecated since 2000 with parts of it moving to other low level audio API, while some of the MIDI functionality remained in later DirectX versions. DirectMusic engine can be considered as an improvement on iMuse in terms of its ability to simultaneously play and manipulate musical events for vertical remixing, but it lacks support for the logical structure for horizontal resequencing of iMuse. Many other systems have been developed over the years, providing different levels of horizontal or vertical adaptivity, with various generative abilities and triggering logic control. For example, a recently introduced Adaptive Music System (AMS) (Hutchings and McCormack 2020) uses a combination of musical rules with agent heuristics for composing and arranging music according to emotional categories, which are linked to game object and game environment through a knowledge graph that is activated based on game actions.

Other Uses of Adaptive Audio

The idea of opening musical composition to chance operations and more recently to interaction with outside contextual information is not limited to video games. The field of music meta-creation explores the use of higher level constraints to guide algorithmic and generative systems according to user specifications (Pasquier et al. 2017). The field of Machine Improvisation combines machine listening with generative systems to create a real-time interaction between a machine and a musician (Wang et al. 2017). Automatic sound effect generation from video is being studied using deep neural networks that learn a mapping from video frames to audio, and using a video encoder to drive a neural network type of sound generator (Zhou et al. 2017). These works differ in terms of the specific types of objects they are modeling and level of synchronization between sound and image. Sensors and depth cameras, such as Kinect, have been used in experimental dance to generate sounds in response to movement (Berg et al. 2012). Other applications of adaptive music include theatre, circus, and various types of interactive multimedia, some of which is addressed by the IEEE 1599 standard for Multilayer Representation of Music Using eXtensible Markup Language (XML) (IEEE SA 2018). The focus of such applications is largely in regards to synchronization and logic of controlling different media assets during an execution of a complex but mostly linear presentation, with less emphasis on generative, algorithmic, or remixing (horizontal or vertical) techniques that are dominant in video games.

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▶ Overview of Virtual Ambisonic Systems

American Sign Language (ASL)

▶ American Sign Language Detection

American Sign Language Detection

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Synonyms

American Sign Language (ASL); Convolutional Neural Network (CNN); Mean Average Precision (MAP); World Health Organization (WHO); You Only Look Once (YOLO)

Definition

American Sign Language (ASL) detection is based on an object detection machine learning algorithm, which helps deaf and hard of hearing people in terms of communication.

Motivation and Background

World Health Organization (WHO) projected that by the year 2050, there would be around 2.5 billion people with some degree of hearing loss (WHO 2021).

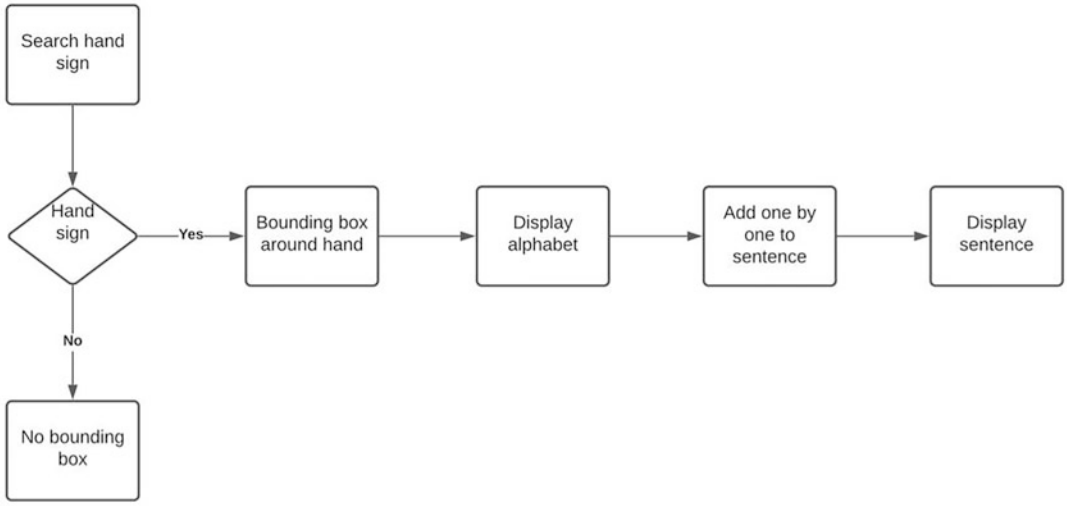
Most deaf anglophones adopt American Sign Language (ASL), which is a common "continental" language. On the other side, British Sign Language (BSL) and French Sign Language (LSF) became obsolete as people started to use ASL. The structure and rules of ASL were discovered in the 1970s and early 1980s. Manual communication was revived in the classroom as many artificial manual codes for spoken English or French. Since the late 1980s and early 1990s, deafer people have sought sign language instruction. Some schools are multilingual (ASL/English) and bicultural (Deaf/Hearing). For example, the deaf anglophone community in Canada uses ASL. Manitoba led the way in 1988, with Alberta following in 1990. Alberta added ASL to its provincial resolution. The Ontario Education Act was changed in 1993 to acknowledge ASL and LSQ as languages of instruction for deaf children (Carbin and Smith 2013).

Due to a language contact situation, ASL was born in the early nineteenth century at the American School for the Deaf (ASD) in West Hartford, Connecticut, in the United States. Since then, schools for the deaf community organizations have worked hard to spread the usage of ASL. Despite the widespread use of ASL, no reliable count of its users has been conducted. According to reliable estimates, there are between 250,000 and 500,000 ASL users in the United States, including a substantial number of children of deaf individuals (Carbin and Smith 2013).

ASL Machine Learning Model

You Only Look Once (YOLO) is a famous object detection algorithm with around 50 Mean Average Precision (MAP), which has a set of Convolutional Neural Networks (CNN) to help the algorithm extract the visual features of an image upon which it is being trained (Kuo 2016; Lu et al. 2020; Redmon and Farhadi 2018). Then with the help of these visual characteristics introduced to the model, the model detects the image in real-time videos/pictures. In this scenario, ASL alphabet images are trained, and then when these alphabets are shown to the camera, the algorithm will detect them.

Deaf and hard of hearing people usually communicate with a person with the help of an ASL interpreter. Due to the Covid-19 pandemic, everything turned out to be virtual, so using ASL interpreters appears to be more challenging. Still, hiring an ASL interpreter, for instance, is not always affordable. Hence, a machine learning model for ASL detection can help the deaf and blind communicate without the help of a human interpreter. For example, there are 26 alphabet hand signs for 26 alphabets and some hand signs for some phrases. A machine learning model such as the YOLO object detection algorithm can be built to detect these signs in real-time by computer vision (Ullah and Ullah 2020).



American Sign Language Detection, Fig. 1 ASL detection process by YOLO

The accuracy metrics used for YOLO are based on the intersection over union concept. The formula used to calculate it is the ratio in-between area of overlap and intersection area. Figure 1 describes the working of the algorithm initially. The machine learning YOLO-based object detection algorithm will look over all the frames coming through the live video, and then the frames will be split into the bounding boxes in the training phase. Then for every bounding box, the model will depict the output, for example, $4 \times 4 \times 18$ (similar to the one in the training phase). Here 4×4 is the grid used for the rectangular bounding box detection, and it is modified as per individual preference and application. The primary nine values will be correlated with the anchor box of 1. Here the immediate value will be the likeliness of an object within the bounding box. Values from 3 to 6 will be the bounding box coordinates for that image. The final three values will disclose where the actual image belongs. The coming nine values are for the anchor box of 2. At last non-max suppression is enforced over the depicted bounding boxes to get the individual depiction of the image (Sharma 2021).

Other object detection models include mobilenetssd, inception, vgg16, and efficient net. These models can be used to build a similar system, but YOLO usually outperforms all the other state-of-art object detection models (Liu et al. 2016). When the camera turns on, the machine learning model in the background will try to draw several bounding boxes and check whether any hand signs of American sign language alphabets are detected. If the machine learning model detects any hand signs, it highlights the hand signs with the bounding boxes and will display the alphabet of the detection. Next, the machine learning model highlights the hand signs with the bounding boxes and then will display alphabets of that detection. Each alphabet that is detected is attached to the top of the screen. Then the machine learning model will repeat the same process on all the frames coming out of the camera and find if any frame can match the hand signs of the ASL.

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Among Us and Its Popularity During COVID-19 Pandemic

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Synonyms

Murder-mystery; Party game; RPG; Social deduction game

Definitions

Social Deduction Game: A game genre that focuses on the use of logic and deductive reasoning to uncover a player's hidden role in a role-based game.

Murder-Mystery: A genre of fictional media that typically involves a crime or death that needs to be solved by the central character(s).

RPG (Role-playing Game): A genre of video games that allow the player to fill and act out certain roles the gameplay provides.

Party Game: A genre of games that facilitates social interactions among a group of members.

Introduction

Among Us is an online multiplayer game that incorporates the formats of social deduction, murder-mystery, RPG, and party game genres. The game was developed and published by the Washington-based American studio *Innersloth* on June 15, 2018, but did not reach popularity until mid-2020s (Carless 2020).

The game's popularity and player base, as of time of writing, continues to grow with the number of active players reaching 3.8 million by late September 2020 (Lugris 2020). A recent update reports that the game grew its user base 1600% in 8 months (Jain 2021). On *Twitch*, a platform where people can host streams and allow others to watch, *Among Us* is ranked third for the number of average viewers over the course of a week with 32,069,859 hours watched as of October 3, 2020 (SullyGnome 2020).

Robinson (2021) reports on the elicited emotions and engagement of the game and finds that compared to more photo realistic games, *Among Us* created consistent emotional reactions – dominantly excitement, curiosity, and relief.

History

Released in June 2018, *Among Us* was meant to be a local-multiplayer mobile game. Initially dubbed "*spacemafia*" on the *iOS AppStore*, the game had a poor marketing campaign and a very small player count. However, this small player count was very vocal about the game's

development, pushing the developers to continue to work on it even after the team's attempts to abandon the project. Throughout the year, *Innersloth* had released several updates leading up to the release of the game for PC in November 2018 and making it available for cross play between PC and mobile.

However, the game's current popularity is credited to the YouTuber and Twitch streamer *Sodapoppin*. He was among the first streamers to publicly show the otherwise unknown game. Other streams quickly followed, further boosting the game's exposure. Through the events of the COVID-19 pandemic forcing gamers to either watch or play more than what they previously could, the amounts of viewers and players for the game continued to skyrocket throughout the following months as it allowed socializing through the stay-at-home orders and social distancing regulations.

Gameplay

Among Us was heavily inspired by other social-deduction games such as *Mafia* (created by *Dimitry Davidoff*, 1986, as attributed by Haffner 1999) and *Secret Hitler* (created and published by *Goat, Wolf, & Cabbage LLC*, 2016), and provides an online multiplayer experience like other games of this genre like *Town of Salem* (developed and published by *BlankMediaGames*, 2018). However, a number of different traits make the gameplay unique and entertaining for both the player and the viewer.

The game offers three maps to play on: a spaceship, a headquarters, and an alien planet base (respectively named The Skeld, Mira HQ, and Polus), as well as a top-down view of the players and the map. The players can interact with the map by exploring and doing various tasks. Despite the top-down view, players have a limited scope of vision so they cannot see everything that other players do or where exactly they are. The game also offers customization to players, allowing them to change their color, outfit, and if they have made in-game purchases, their "pet" that follows them around the map. This differs from other social-deduction games as those characters are not as customizable or do not offer in-game interactivity.

There are two roles: the role of the Crewmate and the role of the Imposter. The objective of the game is for either role to win. If the Crewmates do all their tasks or vote off all the Imposters, then the Crewmates win the game. If the Imposters manage to kill more Crewmates than the number needed that can vote them off, or if a critical emergency timer on a sabotage event counts down to zero, then it is a victory for the Imposter (s). The number of Crewmates left surviving that would enable an Imposter win is one Crewmate to one Imposter. You can have up to three Imposters and a total of 10 players. The minimum number of players you can have in a game is four. Roles are randomly assigned each game. Imposters have a cool down timer for killing and for sabotaging the facility.

Upon finding a dead Crewmate left behind by the Imposter, all players will come together to discuss through an in-game chat client about who is or is not an Imposter in the duration of a limited time period. The Imposter's role during discussions is to lie their way through the game until the timer counts down to zero. People suspected to be Imposter will be voted off by the majority vote. Those who are not voted off continue into the next round and the process repeats again. Meetings can also be issued if the emergency meeting button is activated during gameplay.

Players who are not "alive" or were voted out still have an ability to play, providing another interactive experience different from other social-deduction games. These players appear as ghosts and are able to roam freely around the map and finish their tasks, which helps to aid in Crewmate victory. If the ghost has been an Imposter, they are still able to sabotage the map, but are unable to kill any living player. Deceased or voted off players are unable to communicate with the living but are able to communicate with each other through the in-game chat client.

Socialization

The event of the COVID-19 pandemic in 2020 has caused a shift in social dynamics and institutions. With the advocacy for social distancing, individuals were looking for other ways to communicate and conduct play. A popular outlet for this is video games and one of these video games is *Among Us* (Kriz 2020).

There had been not as much pressure in previous years for the need to socialize and interact with other individuals. While games have been partially viewed negatively before, 2020 has shifted opinions for many officials including the World Health Organization (WHO). In 2013, *gaming disorder* was added to the DSM-5, a collective medical source that describes a variety of disorders and ways to diagnose them (Petry and O'Brien 2013). However, during the pandemic, WHO strongly encouraged the use of video games during the pandemic, allowing a gateway for stress and anxiety relief and an outlet for social interaction (Snider 2020).

Following this, other social games like *Fall Guys* (developed by *Mediatonic* and published by *Devolver Digital* in 2020) and *Animal Crossing New Horizons* (developed and published by *Nintendo* in 2020) grew in trend. It is no surprise, then, that *Among Us* has reached among the top trending games of 2020. In fact, *The Guardian* offered *Among Us* as the "the ultimate party game of the paranoid Covid era" (Stuart 2020). *Among Us* strongly encourages socializing, and not just through its in-game chat client. *Discord*, a real-life chat client geared towards gamers, has hit a spike in downloads since *Among Us* reached popularity since players are utilizing *Discord*'s voice calling system in order to play the game together and make the game livelier with human voices. This encourages social interactions and social bonding with one another, a very important staple to mental health in 2020's world.

Playing over *Discord* and playing voiceless provides different experiences and methods. For example, playing the game through a *Discord* phone call will require you to time your speeches. Most players end up muting their microphones during gameplay until discussion meetings, as to not give anything away. Dead players can talk freely but must mute themselves when discussions are happening. There is a playing order when *Discord* is involved that is not present when players rely only on the in-game chat client – which does not utilize any voice activity and instead focuses on text-based communication. On *Twitch* streams and *YouTube* videos, evidence of one's guiltiness is also much more effectively discussed on a *Discord* call than it is in a game lacking verbal communication. Without verbal communication, members tend to form a bandwagon out of wild accusations just because someone said so with no questions asked.

Among Us has also made it into Internet meme culture and has given rise to a variety of artistic renditions, ranging from animated videos to people making their own Crewmate personas.

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▶ Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

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Analog Prototyping for Digital Game Design

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Synonyms

Iterative game design; Paper prototyping; Physical prototyping; Prototyping

Definition

An analog game prototype is a nondigital preliminary playable object built to test various aspects of a video game. Analog prototypes are especially beneficial in testing the functionality and perception of core game ideas and mechanics in the early phases of preproduction. Analog prototypes may take various shapes such as board games, toys, and street games.

Introduction

Unlike other software, functioning as intended and being user friendly are not enough for video games; they are expected to be fun. As Ferrara points out, games are "inherently negotiated experiences; the designer normally just defines the parameters of play, within which the players bring the game to life" (Ferrara 2012), meaning the prediction of how a game will be experienced by players is quite difficult without seeing it in action. To reduce the risk of not being fun – meaning failure – video games are in need of being tested from the earliest possible step on. As an answer to this need, Salen and Zimmerman suggest an iterative approach to game design, a "cyclic process that alternates between prototyping, playtesting, evaluation, and refinement" (Salen and Zimmerman 2004). This methodology gives designers the possibility to evaluate and adjust their design at each new iteration. The process may start with low-fidelity analog prototypes right after the initial conceptualization and end with high-fidelity digital prototypes, which may even become the final product after refinement and polish. This article focuses on the analog prototyping phase of this process. Why and how do digital game designers use analog prototypes?

Why Analog Prototyping?

In video game design analog prototypes are usually built to test singled out game aspects which can be implemented without the aid of computation and are not expected to reflect other features of the project. A successful analog prototype is built quickly and provides "enough of an experience for someone to grasp the game [or tested components of it] and give feedback" (Fullerton 2014). Media-independent game mechanics may be tested using paper prototypes resembling card or board games (Rollings and Morris 2004), toy prototypes may focus on the playfulness of core mechanics (Gray et al. 2005; Macklin and Sharp 2016), and physical prototypes which are played like traditional street games may offer unique insides to the intended game experience (Adams and Dormans 2012; Waern and Back 2017). Not every aspect of a video game can be tested through analog

prototyping, but certain aspects of every game can be tested by it.

Analog Prototyping Process

Analog prototypes can be created using a wide range on objects. Some more or less standardized components for paper prototyping are meeples, tokens, index cards, tile cards, different types of dice, and of course pen and paper. Digital tools for creating printable graph paper or exporting data from spreadsheets into preexisting card templates can be used to quickly generate prototypes using data from early game documents. The tools for creating toy and physical prototypes are only limited by the goals and imagination of the designers.

Focusing on the iterative design of the overall gameplay experience, Fullerton proposes a four-step analog prototyping process which can be used in video game design (Fullerton 2014): The first step following the initial conceptualization is the "foundation" where the goal is the definition and design of basic game objects and the key procedures, or the core gameplay. The second step is "structure" where the designer starts building the framework of the game. By defining the essential rules and their structural roles in supporting other features, the designer builds an unfinished but functional game system. In the next iteration step, "formal details," new rules and procedures are added to the system to reach a fully functional game. The last step is "refinement" where the designers start to fill the details of the rough but playable system. After several iterations and answering key questions regarding the playability, designers can begin implementing their solutions in digital format.

Strengths and Limits of Analog Prototyping

Analog prototyping is a fast and inexpensive way of testing game ideas by turning them into tangible playable objects. Building an analog prototype forces designers to define game aspects, helps them understand the workings and perception of the game system, and gives them the opportunity to change any rule easily if they do not function as intended. Schell warns against the trap of falling into the temptation of overbuilding a prototype. In his words, a prototype "should be quick and dirty" (Schell 2014). They are test subjects created to be thrown away. According to Ham and Fullerton, compared to digital prototypes, analog prototypes are much easier for game designers to scrap, mainly because they require much less time and effort to build (Fullerton 2014; Ham 2015).

Some aspects of video games, such as game economy and resource management mechanics (Adams and Dormans 2012; Moore 2011), puzzles (Ferrara 2012; Moore 2011), and macro- and microspatial gameplay (Totten 2014) are considered more suitable to be tested through analog prototypes. They also provide a platform to balance statistics tough experimentation and to identify and close possible player exploits (Trefay 2010). Other aspects such as sensory experiences, mechanics involving continuous space and time, and game physics on the other hand are much harder to test trough them. Ham proposes a series of methods, such as creation of flowcharts or state charts to simulate AI and the use of simple heuristics to test motion, to translate video game mechanics into analog game mechanics (Ham 2015). Yet he also warns designers to question the usefulness of analog prototypes if such translations are required. Digital prototyping may be the most efficient way of exploring aspects requiring such translations.

Conclusion

Analog prototyping is especially beneficial in video game design education and in experimental game design. It is an easy, quick, and cheap way of focusing on and experimenting with game ideas without being distracted with complexities of the medium of choice. Despite its limits, its flexibility makes it applicable for the testing of a wide range of features of various types of games.

Cross-References

- ▶ Collaborative Engineering and Virtual Prototyping within Virtual Reality
- ▶ Narrative Design
- ▶ Paper Prototyping
- ▶ Prototyping
- ▶ Psychological Game Design
- ▶ Skull and Roses Card Game

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Animacy

- ▶ Uncanny Valley in Virtual Reality

Animal Crossing: A Causal Game

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Synonyms

Causal game; Real-time game

Definitions

Causal game = A game that is designed to be played occasionally for a relatively short period of time without losing points or competitive advantages

Real-time game = A game that uses real-world time instead of virtual in-game time

Introduction

During the COVID lockdown around the world, many people had resorted to video gaming as an escape into a new world full of many possibilities. One of the most popular games was Animal Crossing: New Horizons. This entry discusses the brief history of Animal Crossing and how Animal Crossing: New Horizons became hugely popular in 2020 during the pandemic.

History

Like Nintendo itself, the famous game Animal Crossing started in Japan with a man named Katsuya Egushi. In 1986, Egushi was able to obtain a job at Nintendo located in Kyoto, where he worked on many games and was known as a level designer for the well-known game Super Mario Bros. 3. Although he was making a name for himself at Nintendo, he was still homesick due to the relocation for his job, which led to the

creation of the first Animal Crossing being released in 2001 (Nintendo Life 2020).

In numerous interviews, Egushi stated that the game was a way for him to be able to recreate the feeling of being with family and friends: "Animal Crossing features three themes: family, friendship, and community. But the reason I wanted to investigate them was a result of being so lonely when I arrived in Kyoto…When I moved there I left my family and friends... In doing so, I realized that being close to them – being able to spend time with them, talk to them, play with them – was such a great and important thing. I wondered for a long time if there would be a way to recreate that feeling, and that was the impetus behind the original Animal Crossing" (Newton 2011).

As many people around the world play Animal Crossing, there is a connection with being able to play with friends and create a virtual world within it. While Animal Crossing is a relaxing game, there is more to offer while playing the game with many different characters and the opportunity to play online.

Gameplay

Animal Crossing has been around since the early 2000s, but the new series of the game became hugely popular years later during the COVID pandemic. While the world was in a lockdown and people were stuck in the house, the new release of Animal Crossing offered people a chance to escape reality and enter a relaxing virtual world. Although people were trapped in their homes and seeing friends was difficult, the game allowed the players to experience being with friends and doing activities through a console. The game became so popular that it sold more than 13 million copies within the first six weeks after its release (Huddleston Jr. 2020).

Animal Crossing is known to be a relaxing game. Not only can you interact with friends online, but players are also able to customize their characters and have endless tasks to help build their community. When the game is launched for the first time, you see an empty island with a character and a tent. Throughout the game, the character works on many tasks, such as building new tools and collecting certain items, to slowly build the island. As the game progresses, new tasks are required, and the players can travel to new islands to collect new materials, play with friends on their islands, and creating vacation homes for visitors. Figure 1 shows how the island looks when the game starts. Figure 2 shows the progression and aftermath of designing a client's dream vacation home.

Within the game, there are concepts that were put in place to help the players.

Animal Crossing: A Causal Game, Fig. 1 The island when the game starts

Animal Crossing: A Causal Game, Fig. 2 A dream vacation home

The first thing many people notice is that the game has a built-in clock that is accurate to the time in the real world. Not only does this help players not lose track of time, it also helps move the game along similar to the real world. For instance, if something is being built or mailed in the game, the players would have to wait a whole day until that task is complete. Along with the clock, the weather and region are also similar to where players are located in the real world. This gives players a sense of reality within the game.

Reviews

Animal Crossing: New Horizons was first introduced in 2020. With the pandemic trapping everyone indoor, the game prospered in numbers and sales. Many people loved the game right from the beginning with all the new things and creations within the game. Some said that after playing it for a while, they ran into a loop which consisted of running around the island, digging for fossils, and fishing on occasions. These chores seemed boring, but it did not last long. With each new update, new tasks kept players entertained. After the pandemic, the game continued to gain popularity as more people enjoyed the gameplay and used Animal Crossing as an escape or a comfort game.

Conclusion

In summary, the history of Animal Crossing started when a game developer left home and became homesick. The developer was able to turn his feelings of missing his friends and family into one of the top-selling games. The global pandemic further boosted its popularity and cemented its legacy in video gaming (Carpenter 2021; Claiborn 2020).

Cross-References

► Video Games

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Animal Crossing: New Horizons and Its Popularity During COVID-19 Pandemic

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Synonyms

Life simulation game; Nonlinearity; Open-world game; Social game

Definitions

Social game: A social game (sometimes referred to as social simulation games) is a game in which one of the core themes revolves around maintaining and having meaningful social interaction with both NPCs (nonplayable characters) and other players if the game is multiplayer.

Life simulation game: Life simulation games usually have a focus on gameplay that allows players to have meaningful and complex interactions with the world around them. This interaction with the game's world usually addresses common life themes, such as farming, fishing, NPC social interaction, resource gathering, money-making, and many other themes found in day-to-day life.

Nonlinearity: Nonlinearity in games results in said games not having a set path for the players, and the game can be explored differently for all players. Games that do not fall into this category typically restrict the player to a strict linear progression during a playthrough.

Open-world game: Open-world games have a large, complex, and interesting environments for the players to explore and travel throughout. These games typically do not restrict player movement to a linear progression or path and allow the player to explore the openness of the world at their whim.

Introduction

Animal Crossing: New Horizons was developed and published by *Nintendo*, and it was released in March 2020. The game became extremely popular due to its long-awaited arrival, but it was also the beginning of the COVID-19 pandemic issues which forced many people indoors. Many players found solstice in the simple pleasures of this game, and it became one of the largest releases in recent years (Bogost 2020). The game was released solely for the *Nintendo Switch* gaming console. *Animal Crossing: New Horizons* is the fifth installment in the *Animal Crossing* series. The other games in the main series and the spinoffs are:

- Animal Crossing (2001, released for Nintendo 64)
- Animal Crossing: Wild World (2005, released for Nintendo DS)
- Animal Crossing: City Folk (2008, released for Nintendo Wii)
- Animal Crossing: New Leaf (2012, released for Nintendo 3DS)
- Animal Crossing: Happy Home Designer (2015, spinoff, released for Nintendo 3DS)
- Animal Crossing: Amiibo Festival (2015, spinoff, released for Nintendo Wii U)
- Animal Crossing: Pocket Camp (2017, spinoff, released for iOS and Android)

The game has an ESRB rating of E ("Animal Crossing" n.d.) as it appeals to almost all audiences and contains no adult themes. The *Animal*

Crossing series is known for its complex world building through its life simulation gameplay (Kim 2014); however, *Animal Crossing: New Horizons* builds upon this by adding an interactive and widely accessible multiplayer aspect. The core mechanic of the series is that the game time runs on real time which adds a more immersive layer of complexity to the series.

Gameplay

The gameplay for *Animal Crossing: New Horizons* is very simple and complex at the same time. The pace of the game is very relaxed and slow which allows for many things to be completed in one session while not feeling too rushed. There is a vast pool of activities that the player must choose from. The activities allow diverse gameplay that the player can decide upon. The open-world aspect of the game also allows the players to complete most tasks or activities at any point which prevents the game from feeling too restrictive or linear. The activities and tasks available to the player range from collecting fossils, fishing, catching and collecting rare insects, building relationships with player NPCs, foraging, collecting resources, earning money, and much more (see Table 1). The main "questline" of the game is progressively paying off loans to increase the size and storage space of your home.

Relative to other life simulation games on the market, *Animal Crossing: New Horizons* uses common themes and activities for the player that resonate throughout many other games in its genre. However, the unique spin that makes the game a one of a kind is its diverse and complex villager NPC system. As of October 2020, there is a total pool of 391 different and unique villagers in the game. Villagers are sorted into different personality categories that affect their dialogue and interactions with both the player and other NPCs. Villagers will slowly come to your island, and through the discovery of vacationing villagers on other islands, you also have the ability to ask them to join your island. This complex system allows for the player to decide what character traits the NPCs in their game have, and it allows for a more diverse and customizable world-building experience.

Animal Crossing: New Horizons and Its Popularity During COVID-19 Pandemic, Table 1 Activities in the game

Activity	Detail
Collecting	Fossils, fishing, catching bug and insects, foraging plants, currency, and recipes
Building	Town buildings, changing island topology, planting plants, and designing home
Crafting	Tools, furniture, clothing, and accessories
Character customization	Collecting and changing clothes, hair styles, and accessories
Travel	Visiting vacation islands and visiting the islands of other players
NPCs	Collecting/Inviting NPCs, gifting, trading, and building relationships

Reception and Effects of COVID-19

The reception of *Animal Crossing: New Horizons* was overwhelmingly positive due to both the quality of the game and the timeframe in which it was released. The game debuted on the market on March 20, 2020, and by the end of the month, *Nintendo* had sold over 11 million copies. In North America, the game became the best-selling title of March 2020 and the second-best-selling title of 2020 as a whole (Grubb 2020). As of June 30, 2020, the title has sold more than 22 million copies, making it the second-best-selling game on the *Nintendo Switch* system (Byford 2020).

Other than the quality of the game, the timing in which it was released played a significant factor toward its success. The game was released during the start of the worldwide COVID-19 pandemic. Many communities and players throughout the globe started quarantining, and the game provided an outlet for escape and relaxation that many individuals desperately needed during these times (Buchanan 2020). Although some previous versions of the game were offered to have

mechanics linked to addiction (Scully-Blaker 2019 on *Animal Crossing: Pocket Camp*), this specific version of the game offered players "temporary escape" from the risks of the pandemic, as well as a way to "get rid of loneliness" (Zhu 2020). Many individuals found interesting ways to use the game for events such as business meetings, weddings, birthdays, and much more. The widespread popularity of the game resulted in academic interest in its reception based on social sciences and humanities research (Leporati 2020). These endless possibilities and calming atmosphere for escape allowed for the game to become one of the most popular and impactful games of its time.

Cross-References

- ▶ Among Us and Its Popularity During COVID-19 Pandemic
- ▶ Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

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Animal-Computer Interface

▶ Engaging Dogs with Computer Screens: Animal-Computer Interaction

Animation

▶ Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science
▶ Preserving the Collective Memory and Re-creating Identity Through Animation
▶ Super Mario Galaxy: An Overview

Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science

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Synonyms

Animation; Emotional Intelligence; Neuroscience; Social emotional learning; Visual literacy

Definitions

Animation: is the emotional energy in motion of a visual thinking. The illusion of life by making sequential drawings (or 3D representations) of a continuing action and projecting their photographs onto the screen at a constant rate.

Neurocinematics: refers to the neuroscience of film, term coined by Uri Hasson from Princeton University, who studies the effects on the viewer's brain activity when watching a given film.

Introduction

Why does it matter what we know about emotions when making movies? Can an animation help us to understand them better? Even if we naturally learn by telling stories, people may forget words and events, but they will never forget how something makes them feel. Movies touch our hearts in the same way they touch our minds.

> Whether we hope to spot concealed emotions or seek compassionate connection, our ability to see and respond to others' often unspoken feelings is central. This ability can be trained. We provide the tools. Paul Ekman

The use of animation as a creative media to enhance communication implies to study relationships, how we connect with each other and how our brains make connections with the information that collects. Neuroscientists acknowledge that we humans need to make sense of our reality, for what we make relationships depending on our perception (Beau Lotto 2015). The dangerous and magic point of this fact is the brain does not distinguish between the imaginative perception from the real perception. If our well-being depends on how we see, perceive the inner/out world, we need to experiment and study how we make stories in order to deconstruct them and get to observe from different angles, not just one reality but may be many others.

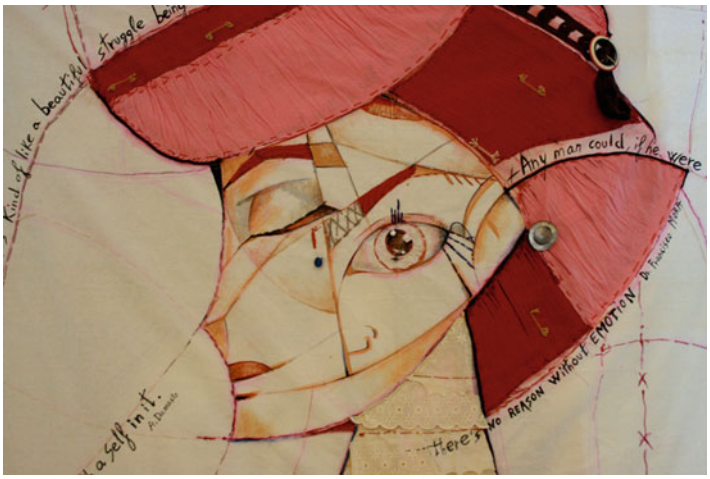
Emotional regulation is extremely relevant since influences our decision-making and problem-solving skills. Our well-being or happiness depends on this mysterious ancient world of emotions connected to our way of thinking, and we can explore it through animation. Studies from Talma Hendler, Zack Jeffrey, or Uri Hasson evidence of how watching movies activate specific areas in our brain related to different emotions. This new neuroscience of film making is known as Neurocinematics (Hasson 2008). There are no specific studies regarding to the positive effects of the creative process of animation, especially focusing on how animation and emotions are connected during the art production.

Labs such as Lotto Lab in the United Kingdom, the Animated Learning Lab in Denmark, or the Film Board of Canada have been working on this issue by developing new paradigms of teaching connected to sciences and film production. They include into their teaching human values such as mindfulness, compassion, resilience, and emotional intelligence. We consider animation as a social emotional learning tool; animation is the emotional energy in movement that provides the illusion of life, a soul, and a fantasy world as real. It is an artistic thinking-feeling media, which provides great opportunities to experiment, by playing, with different perspectives, creativity and innovation, and new worlds.

Before going into the current fascination with visual effects and the most advance technology in movies, we should recall how the art of film making started with silent feature films such as from Méliès, *A trip to the Moon* (1902) or Chaplin's *The Kid* (1921). In these films as many others of that time, the main tools that directors could count on, to show the audience an idea or feeling, were the movement, action, and music before dialog appeared. Animation happened even before those movies were produced, in the Upper Paleolithic caves of Altamira or Chauvet (France, ca. 30000 BC). Those were the first attempts to express the idea or feeling of how an animal look like, furthermore, in movement. Some anthropologists and psychologists of neuroaesthetics as Marcos Nadal (University of Vienna 2014) believed that those representations were probably like plays where they could rehearse a situation like hunting. Those cavemen were learning through visual storytelling, most likely making their own sounds and pantomime, before any language existed. They made

Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science, Fig. 1 Film animated strip

Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science, Fig. 2 Textile art for a character design. Re-construction of thyself



associations between what they saw and the drawings on the walls with a meaning.

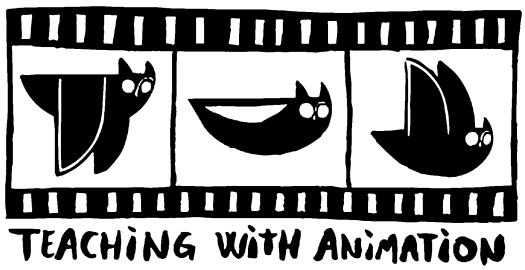
Animation can be as abstract as in its origins and go beyond the limits of the physicality of live action movies, for which we usually see a hybrid of productions that need animation to recreate the impossible scenarios that we imagine in our brains, such as *Avatar* (James Cameron 2009) or possible recreations from the past, such as *Jurassic Park* (Steven Spielberg 1993). Directors like Ray Harryhausen (United States) and Jan Švankmajer (Czeck Republic) were experimenting live action with animation before big companies like Disney produced the well-known *Mary Poppins* (1964), *Who Framed Roger Rabbit* (1998), and *The Three Caballeros* (1945). Animation acts as the bridge between reality and fantasy, and the imaginary perception and the real perception. It makes us believe the most abstract forms or realistic dreams as real life, thanks to the emotions which connect us. The short movie *The Dot and the Line: A Romance in Lower Mathematics* (Chuck Jones 1965) is a very harmonic story where we see through the simplest elements of visual composition, the pure expression of feelings in movement.

In the following lines, we will briefly present the relationship between animation, neuroscience, and emotions, which we use during film productions at different levels. We obtained very positive results that motivate us to share and ask scientists to keep working with artists, like Paul Ekman who has explored with his studies the universal signs of emotions and facial expressions in different cultures. Antonio Damasio pointed out that scientists record life as it is; yet, artists express it as it may or may not be. Artists can be the scientists of pre-conceiving life.

> "The greatest scientists are artists as well" Einstein. (Calaprice 2000, 245)

This is our vision, how we can use the knowledge of producing movies to change our perception, to learn about life understanding our emotions, so the relationships that we have with the *self* and the external world (Fig. 2). Rewire our brain with a tool that helps to rewrite our story to become fully alive and make sense of our lives.

Methodology: Working Beliefs-Feelings-Actions Through Animated Productions



In this section, we share our observations and work method during the creative process of making an animated film.

We collected data from the Animated Learning Lab in collaboration with educational institutions from different countries, such as San Carles Fine Arts in Valencia, Spain; independent artists such as George Mcbean (UNICEF) and creative professionals, who have been working on tailoring animated workshops for students of different ages, from toddlers to postgraduate students. This makes a richer experience at the time to exchange and contrast ideas, which shows us interesting ways in which animation is a very powerful tool for building social relationships and increasing creativity. To answer why we connect animation, emotions, and neuroscience, we will start explaining the relationship between our brain and emotions.

Scientists such as Richard Davidson (University of Wisconsin) Daniel Siegel (Mindsight Institute, California) or Joe Dispenza (DC) have been studying neuroplasticity and researching the effects of meditation and emotional regulation for an optimal learning and well-being. As we mentioned before, emotions affect our decision-making, if we learn how to identify the emotions and regulate them, we will be able to develop resilience and increase our sense of fulfillment and contentment. We found that animation can be an excellent media to learn and regulate our emotions, understand different perspectives, and be more conscious about our feelings and beliefs.

The most recent Pixar movie, *Inside Out* (2015), is an excellent sample of the importance to understand the relationship between emotions and thoughts with behavior. Furthermore, some schools are using the movie to talk about and identify the emotions. By watching this movie, we learn to identify four from the primary six emotions that Antonio Damasio classified in his research (Damasio 1999). We get to know why and how the characters behave, what is inside our heads and what kind of feelings and actions emerge when one emotion is in control. We understand the importance of accepting and balancing negative and positive emotions because they need each other. The same thing applies to the question of being more rational or emotional; both go hand-in-hand and work together as we can see in *Reason and emotion* (Disney 1943). Some great films as *Party Cloudy* (Pixar 2009) explore feelings and ideas, friendship and resilience, with a clear reflection by using images over words. *Luxo Jr.* (Pixar 1986) was a revolutionary experiment using procedural animation, where John Lasseter applied the classical principles of animation to 3D characters in order to provoke emotions. Most recently, in the independent film-making arena, we find a movie which has a program for teachers to share wisdom about life, *The Prophet* (Salma Hayek 2015).

The field of neuroplasticity explains how our brain is capable of change with every experience and by repetition, creating new synapses and patterns that can determine new behaviors (Davidson 2008). Animation is all about repetition and focus; it is a transformative process where we work connecting our minds to our bodies. During any creative process, the energy flows where our attention is focused (Mihaly Csikszentmihalyi 2008); some people are more kinesthetic, others are attracted to sound or are more verbal; these are some of the multiple intelligences that Howard Gardner (Harvard 2006) acknowledged, all can be explored during the creation of an animated movie as if it were a mindfulness practice.

Animation can be a practice of mindfulness, since animators need to observe outside of themselves, in order to be able to understand the character that we must animate, or have enough

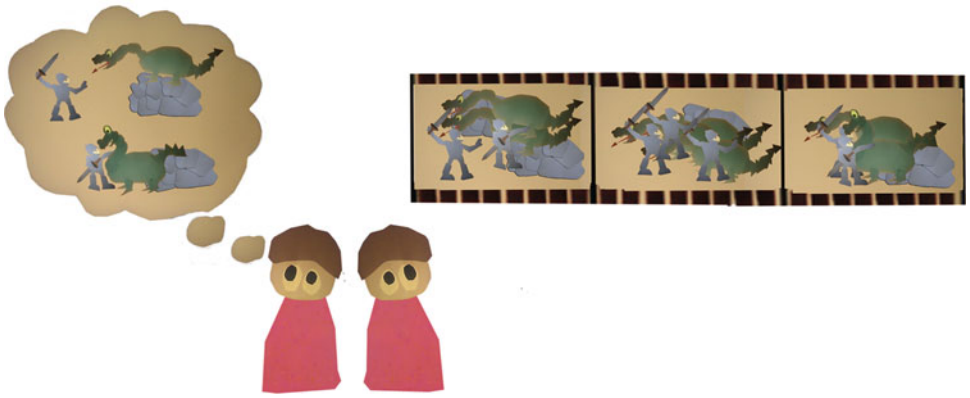
information to be able to design a new original character, environment which has to be believable and engaging to the audience. This engagement happens because our empathy and mirror neurons activate when a speaker and listener interact (Hasson 2010) (Fig. 3). Despite very subtle differences between cultures, is our basic human essence to connect through empathy; Paul Ekman (*Emotions Revealed* 2012) has been working for major animation studios due to his relevant studies about facial expressions, emotions, and deception. Animators have been using his knowledge to better understand the nuances of expressing feelings within different contexts and situations. This is relevant to exaggeration and having gestures to entertain the audience, as the story unwraps. Our understanding about the story itself is a reason for case study; to question beliefs, decide which emotions intervene and what actions are going to happen to resolve the conflict. Life is presented as a conflict to resolve, with a touch of imagination. Walt Disney Studios used to test future animators with an assignment where they had to express different feelings and emotions using a sack of flour. A clear sample of how we can learn about emotions from the inside out is by doing, as we do from outside in, by watching movies.

To work on a production, we set up groups of three or four students, depending on their age and interests. Each group had to discuss an idea and make a film out of it. Different roles were distributed amongst themselves, if they are not children under 9–10 years old. Ateliers are taught in a constructivism learning method (Vygotsky), to animate in a very intuitive way, by playing with the software and receiving small lessons and support from the tutors. We focus on four main animation techniques: pixilation, cut out, clay, and 2D, to keep them in touch with analog materials and avoid working just with computers. We encouraged the importance of using kinesthetic techniques when possible, since it helps to focus. The rewarding system of the brain activates when students see a physical and visual product after their learning experience.

Animators develop the four main components that Daniel Goleman acknowledges in his definition of emotional intelligence (2005): self-awareness, social awareness, self-management, and relationship management.

Naturally our brain is plastic and shapes itself by experiences; it is always transforming and creating new synapses, even as we get older. When we work on making movies, we put ourselves as directors or animators in hypothetical situations that, either, are real memories or fantasies. In either case, they are an excuse to experiment in a safe context, situations which we could be involved in, provoking: reactions and, inducing feelings and ideas that we can question by reflecting, especially working in groups where different perspectives are factored in.

The creators have to think and feel the way their characters must behave. During this process,



Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science, Fig. 3 Illustration of speaker-listener when telling a story

they are not just ***passive*** **observers** but ***active*** **protagonists**. As a result, the learning experience is stronger and their effects are more intense regarding comprehension to why a character acts in a certain manner, and how they should express ideas and feelings in accordance with that behavior. The results in comprehension of emotional status are higher than when watching movies. While watching a film, each viewer makes a lecture of the scene based on his perception (from his/her background). In other words, they bring their vision from what they personally have lived; by doing animation, they *become* the character, forcing them to get his mindset with all its traits. Feelings are no longer a personal interpretation but a rehearsal for *being* the character, even though there may be certain level of subjectivity while acting.

Animation acts as a metaphor to transport the ateliers to live other people lives, through their minds and bodies. We usually hear" You don't understand because it never happened to you" and somehow this is true since the process of embodying feelings and ideas is always more real when one has lived a similar personal experience. The reason is there is a trace of that past event through all the senses, instead of being just a hypothetical thought or imagination. In this matter, the creative process is more important than the quality of the final result, because it makes you gain knowledge by experiencing instead by just listening or viewing (Fig. 3).

At the end of the production students, learn technical aspects related to animation and film making than can be applied to reflect on real life. Movies are audiovisuals expressions from reflections about life, a work in progress; and we create our own stories as recreations of past, present, or future events. We become the architects of personal realities, by editing those moments and putting them together to make sense of what we live (Lev Kuleshov 1920). Our brain does not distinguish what is real or fiction, and perception and cognition are crucial in understanding emotions and getting an optimal communication within the self and others. We edit and change our realities due to personal perception and the fragmentation that occurs in our brains when processing data; this is a whole new area of study, the cognitive neuroscience of film (Jeffrey Zack 2014).

> Life is a tragedy when seen in close-up, but a comedy in long-shot. Chaplin (1889–1977)

In making movies, we must be aware of the meaning and function that every artistic component adds to the film. In animation, we work with what big studios call color script, which shows the film's colors and lights visualized in key frames from the primary scenes. Nowadays, we can find the whole movie compressed as a *barcode*, providing the whole spectrum in one image. Animators learned to evoke emotions by using different technical elements of composition such as color, warm for love and positive feelings, more blue or darker for sad ones: in *Beauty and the Beast* (Disney 1992) the castle changes from very dark bluish colors during the spell, to bright and warm towards the end of the film. Round shapes are more suitable for children; they are soft and calm as we see them in *Lilo ad Stich* (Disney 2002), while more angular shapes convey a cold and aggressive feeling. More light is associated with happy and relaxed situations, such as in *Tangle* (Disney 2010) where everything is inspired by the painting of Fragonard; the main colors are pink and soft with an especial glow. Music is extremely relevant as well as many other elements, such as rhythm. Animators and directors start to be more aware of the psychological and symbolic meaning of these components as they work on productions. Even camera movement can create and enhance different moods.

To summarize, life in animation is a safe game where we play somebody else; we are free and focus on what we do. Being aware of what happens brings a more peaceful status of relaxation to face problems and make decisions. We work on resilience and the relationships between the world and the self, as well as the connections between our thoughts, feelings, and actions, in order to reach balance. Animated movies can teach us how to feel like children again and inspire us to become our better selves, even when we are already grown-ups thanks to neuroplasticity. It is a chance to find ourselves in somebody else's eyes, so we can meet others within ourselves by

empathy, which is the key to our emotional system. Animation is an excellent art form for self-awareness and self-development, which we can use for children and adults. Filmmakers and professionals of other visual fields must take bigger responsibility of their influence in people's lives, through their movies, especially children. Animation is more than an entertaining media; it is a visual language of emotions and feelings, worth to research the sciences of its effects in how we make up stories in our minds in order to make meanings and sense of our lives, starting by how we perceive the world.

Results

- Animation improves our cognitive functions and awareness of being.
- Students or professionals learn about emotions and feelings (especially the difference)
- It enhances social skills such as cooperation, compassion, tolerance, listening, and teamwork.
- Animation provides a more natural method to reflect on actions by having fun, without judgment.
- Communication becomes better within the teamwork by sharing and listening.
- Expressing feeling through animation encourages students to find their voice when there is some impediment or difficulty, physical or psychological.
- The students raise their self-esteem and feeling of reward by producing a final product.
- Learning skills, as concentration, focus improve considerably after a program is complete.
- Students start to develop a personal mindset with a critical view to question audiovisual information and beliefs systems.
- Animation students get greater knowledge and comprehension of visual literacy when watching or producing movies.
- Creativity increases in all cases, including the most introverted animators.

Conclusions and Discussion

Working with animation provides the tools to train our minds and bodies thanks to neuroplasticity, by applying the emotional intelligence. It can be considered as a medium for cognitive therapies.

It is a bridge between sciences and arts.

Animation is an excellent medium to teach visual literacy and develop critical minds to avoid manipulation.

Within art therapy, it works as an excellent new approach with autistic children and any other condition that is an obstacle to communication.

It is a mindfulness media and tool to put it in practice and bring consciousness from the unconsciousness.

The creative process of an animated movie helps to develop important social skills.

Animated movies serve as metaphors to communicate when language barriers are an impediment. It can be an alternative language to linguistics.

Animation should be considered a social emotional learning tool to be incorporated in regular curricula to implement knowledge about emotions.

Animated productions open new ways of communication, contributing to the creation of happier communities with the necessary tools to obtain an optimal sense of resilience, in order to cope with life's challenges, learning to be humans. Animation is a social emotional learning media, extremely powerful to study deeper the cognitive effects in our brains and minds during art production, which can bring us a better understanding of how we see the world from different perspectives.

Animation can be an important storytelling media to be aware of our thoughts and feelings, to reflect upon them and understand the stories that our brain creates, since apparently its default mode activity is story-making (Mehl-Madrona 2010).

> I am convinced that animation really is the ultimate art form of our time with endless new territories to explore. Glen Keane. http://www.awn.com/news/glen-keane-creates-nephtali-short-paris-opera

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Animation Scripting

▶ Character Animation Scripting Environment

Anomaly Detection

▶ Fall Risk Detection in Computer Vision

Anti-cheat Protocols

▶ Secure Gaming: Cheat-Resistant Protocols and Game History Validation

Anti-phishing Attacks in Gamification

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Synonyms

Social engineering attacks, Spear phishing, Phishing attacks, Cybersecurity attacks, Phishing and game attacks.

Definition

Phishing is a social engineering attack which aims to manipulate people and encourage them to expose their confidential information. There are many different types of phishing attacks such as spear phishing, whaling, vishing, and smishing.

Introduction

Cybercrime is becoming a widespread problem that is posing an increased risk due to the increasing number of devices such as smartphones that are connected to the Internet. There is an increase in the usage of smartphones for a variety of applications, such as browsing the Internet, gaming, social networking, online banking, and attending to emails. The past three years have seen an increase in smartphone usage for email applications by 180% (Heinze et al. 2016). Furthermore, banking users will use their mobile devices to manage their current accounts over 2.3 billion times – more than the cumulative total of desktop PCs, branch, and telephone banking users (Heinze et al. 2016). However, less than 33% of mobile users have installed antivirus software on their devices when compared to the 91% level seen for laptop users. One reason may be that 45% of mobile users do not see cyberattacks on their mobile devices as a threat. The rise in the use of smartphones, their limited security, and the lack of end user knowledge increase the risks of victimization. This directly affects the gaming applications while using smartphones.

Phishing is one of the social engineering attacks which is the psychological manipulation of individuals into revealing confidential information (Anderson 2008). Phishing is a common form of identity theft and it is among the highest-ranked cybercrimes, costing organizations an average of $3.7 million per year in USA (Greenberg 2016). A study by a British government–backed cybersecurity firm found that phishing attacks cost British users £174.4 million in 2015 (Greenberg 2016). The most common phishing uses emails, chats, or websites along with attacks game applications especially among online and network games to get valuable information. A phishing attack disguises itself as a harmless request from a trusted sender that tricks its victim into sharing personal information. It can be thought of as an attack that uses social engineering to target the gullibility of people. Social engineering is "the use of non-technical means to gain unauthorized access to information or computer systems" (Thompson 2006). Phishing attacks are in theory a well-engineered social attack to extract valuable personal information from individuals. Phishing attacks tend to be challenging to detect by inexperienced people. This is due to the fact that they pretend to be coming from well-established and trustworthy senders (Thompson 2006). Most people assume that phishing attacks are aimed to financially damage individuals alone. That may be true; however, their damage is actually far more deep rooted and long lasting. This is because, individuals who have been harmed have their trust significantly diminished in electronics and

business from which the phishing email appears to have come (Robila and Ragucci 2006). This in turn means the reputation of that business will be damaged, causing loss of its loyal customers, since those customers tend to associate the business with phishing attacks and ceases to use the services offered by that business (Sullins 2006).

An investigation by McAfee illustrated that employees working in finance, accounting, and human resources were among the worst in detecting phishing attacks and responding appropriately to them (Cochin et al. 2014). This then raises the question of how such departments, with so much access to sensitive data, should guard their organization against phishing attacks. Multiple sources from renowned scholars strongly believe that the best way to defend against such attacks is by using a multilayered technical anti-phishing defense system. Nevertheless, the biggest part of this defense mechanism still remains well educating and training employees of an organization to be able to recognize phishing attempts and immediately respond by reporting them to the members of the IT team (Butler 2007; Hong 2012; Swapan 2012).

Due to the severity of cybercrime at personal and national levels, many countries have introduced cybercrime laws. In the UK, Sections 41–44 of the Act, which amends the Computer Misuse Act 1990 (Thompson 2006), stipulates that offenders will face tougher penalties for committing cybercrimes intended to cause serious damage. The US Computer Fraud and Abuse Act (CFAA) was enacted in 1986 and its penalties can be imprisonment for not more than five years and/or a fine of not more than $250,000 for individuals (Robila and Ragucci 2006).

Gamification Solution

Phishing has been a complex phenomenon and therefore it is not possible to single out a solution to avoid it. Therefore, the risk of phishing can be reduced through the education and training of users and by suitable technology.

There are numerous technical and nontechnical solutions that have been suggested to reduce the risk of phishing. The solutions are based on the latest studies in the field in addition to the best practices and awareness in the field. E-mail phishing attacks have evolved from being purely technical, consequently highlighting the need for defense mechanisms that go beyond purely technical controls. Thus, security in this application must be viewed using a holistic perspective to integrate technology with aspects of human behavior.

A survey of the market reveals that there are many commercially available solutions tailored toward fighting fishing attacks. Despite their widespread availability, tools to detect automated e-mails have limited capabilities (Fette et al. 2007) (Zhang et al. 2007). conducted a study on ten anti-phishing tools and found that only one of them was able to correctly detect 90% of automated emails in a certain trial. However, a further investigation showed a false classification accuracy of 42%, implying that it incorrectly classified 42% of emails. The reason for this difficulty in detecting potential phishing attacks is that phishing attacks are constantly evolving to take more complex forms. As a result of this, it is very difficult for universal anti-phishing tools to detect and protect the user from all forms of attacks (Zhang et al. 2007). Instead, the readily available tools merely reduce the risk of phishing attacks without offering a comprehensive and accurate detection of all possible attacks (Dodge Jr et al. 2007) (Dodge and Ferguson 2006) (Downs et al. 2007). classifies the incorrect detection of legitimate and phishing emails as being false positive and negative, respectively. They also found that anti-phishing tools can never give complete protection against either form of false detection of emails. Therefore, users should make their final decision on the potential classification of emails using their own knowledge and experience rather than solely relying on the anti-phishing tool. This can prove to be a challenge as user behavior and knowledge is unpredictable and there is no systematic way to remove the risk associated with a lack of appropriate user knowledge on the matter (Dodge Jr et al. 2007). This shows that complete protection is only achievable by having an idea of the behavioral response of a user, be it through education or

knowledge of the best practices. It is thus important to understand what exactly makes people susceptible to phishing attacks to help us develop all anti-phishing tools, most importantly awareness and education of the issue (Kumaraguru et al. 2007; Sheng et al. 2007). Further research in the vulnerability of users to phishing attacks is needed to develop complete anti-phishing protection tools that can offer an end-to-end solution against a variety of phishing attacks.

Despite the reduction in the potential of phishing attacks offered by technological solutions, user-level protection still proves to be the most effective form owing to their high vulnerability due to a lack of knowledge in the field (Downs et al. 2007). This claim is proved by many researchers in the field who conclude that there is a definite need to improve user awareness on the matter to increase the chances of success of fighting against the attacks (Downs et al. 2007) (Kumaraguru et al. 2007) (Sheng et al. 2007). A study conducted by (Forte 2009) finds that relying solely on technological barriers against phishing attacks offers limited protection as the attacks are typically designed to work directly on users and exploit their lack of knowledge. This shows that it is of utmost importance to educate users on the importance of verifying the legitimacy of phone calls and emails that they receive. Phishing awareness has been discussed extensively in the literature, with some sources referring to recommendations known as best practices that users can follow to limit their exposure to potential attacks. They also discuss how these best practices can be taught to a wide audience in an effective manner.

"Gamification is defined as a process that integrates game elements into game fewer objects in order to have graceful characteristics" (Yohannis et al. 2014), this means that gamification uses game elements (badges, levels, time constraints, etc.) in a nongame environment to make the system have graceful characteristics, meaning it is not a full game. It only uses elements from games. Deterding et al. (Deterding et al. 2011) say that gamification refers to the use, design, elements, and characteristics of games in a nongame context. This means that gamification is in between a full game and parts, gaming and playing.

A way to play a game while having fun, but it is not a full game. The effectiveness of teaching procedural and conceptual knowledge using games has been discussed extensively in the literature (Rittle-Johnson and Koedinger 2002; Gee 2003).

Researchers have put forward several blacklist−/whitelist-based and heuristics-based defense mechanisms to protect against phishing. Entities such as PhishTank (PhishTank) and Anti-Phishing Working Group (APWG) have compiled reports on authentication services and phishing. Over the years, many tools have been developed which are designed to safeguard against the most common phishing attacks: browsing services like Microsoft SmartScreen Filter, Norton Safe Web, McAfee SiteAdvisor, and Google Safe Browsing are just some of the tools developed to this end. Nonetheless, phishing practices have evolved in sophistication in tandem with defense systems, often staying one step ahead in the game of avoiding notice and bypassing safeguards (Yue and Wang 2010). The struggle between phishers and anti-phishers is an enduring one.

Anti-Phishing Phil

Sheng et al. (Sheng et al. 2007) presented the development of an online game called "Anti-Phishing Phil." Anti-Phishing Phil is a game developed to educate users about phishing. This game teaches users how to spot phishing attacks. The player (user) is playing as a fish named Phil. Phil is hungry and wants to eat worms, so he can become a bigger fish. The problem is that the worms are associated with URLs. These URLs can be either to legitimate websites or to phishing websites. The player needs to choose the right worms to eat before running out of time. Phil's father is guiding the player by giving tips on how a user can detect phishing URLs, thus using entertainment for the purpose of educating the users about phishing. Anti-Phishing Phil uses rounds, scores, lives, and time for the purpose of entertainment. If the user chose a good URL, then the user is going to achieve points. If the user chose a phishing URL, then the user is going to lose

points. This is with the purpose of educating about phishing threats.

Users can be educated by means of a game to enhance the learning process (Sheng et al. 2007). For instance, they can be presented with a series of URLs: they gain points for correctly identifying safe URLs and lose points for clicking phishing links. The results of the game carried out by (Sheng et al. 2007) showed an increase of 60% in the detection of phishing links, thereby showing the successful transfer of knowledge of phishing attacks onto users. Another example of a study that aims to educate users using a game is done by (Zhang et al. 2007). This game gives users clues on how to identify URLs that can potentially be used for phishing attacks, such as teaching users to rely as much as possible on the links on the first page of search engines as these are typically the most reliable ones. Despite increasing the user awareness toward potentially harmful URLs, a limitation of this approach is that it relies solely on detecting the legitimacy of the URLs without making reference to the detection of actual phishing messages. The outcome of the game was also determined using a scoring system to increase user interest in the issue. Teaching the concepts using this interactive approach (as shown by (Sheng et al. 2007)) aims to educate users in a dynamic manner where they aim to score the highest score possible, thereby increasing user interest in the underlying concepts aimed to be taught and overall retention of information (Quinn 2005).

Mobile Game

A new mobile game, at a prototype level, is developed by Arachchilage et al. (Arachchilage and Hameed 2017) with the aim to teach and train individual's minds to defend themselves from the different techniques used by phishing attacks. This game is centered around the purpose of improving the user's behavior toward subconscious detection of the threat of the phishing attack and hence avoiding it. The study on the effectiveness of this mobile game on teaching ordinary people to thwart phishing attacks has shown a significantly promising result. The study further brought to attention that the avoidance behavior of individuals was heightened by the individual's own threat perception, perceived severity, perceived susceptibility, self-efficacy, and safeguard effectiveness. This is while the cost of safeguarding provided an adverse impact.

"Smells Phishy?" Board Game

On the front of anti-phishing, board games have been developed to increase the player's awareness regarding online phishing scams. One particular board game, by Baslyman and Chiasson (Herzberg 2009), was used in the study which showed people who played the game now better understand what phishing scams are and how they can best avoid falling into their traps (Arachchilage and Hameed 2017).

Embedded Training Email

Kumaraguru et al. (Kumaraguru et al. 2007) have invented and developed a new technique called embedded training email system, in the quest to teach people how to protect themselves against phishing attacks, focusing on the use of email. Further experiments have illustrated that two embedded training designs work much better than the current use of sending security notices (Arachchilage and Hameed 2017).

Automatic Content Generation

Tseng et al. (Tseng et al. 2011) have focused on a game project that turns the assessment of the content of a website into a game in order to teach users how to detect phishing. This includes describing stereotypes features of a phishing attack by coming up with a hierarchy frame for the phishing attacks. Furthermore, other properties of the frame model, such as its instantiation and inheritance, enable the extension of the phishing pages, which in turn increases the game content. The test on the effectiveness of this technique was carried out by the use of an anti-phishing educational game, which resulted in most experts and participants satisfied with this system.

Self-Efficacy

Archchilage et al. (Arachchilage and Love 2014) have intercalated both conceptual and procedural

knowledge into their innovation approach into gamification. This focuses on their effect on the player's self-efficiency to avoid phishing attacks. Therefore, the aim is to add self-efficiency into the game frame in order to make the game better equipped for teaching anti-phishing techniques. However, this comes with the challenge of actually making a successful transplant of self-efficiency into the body of the game. This is achieved by teaching individuals how to well differentiate true URLs (uniform resource locators) from fake ones, using elements from a theoretical model (Lin et al. 2015). This model has continually shown that the interaction of conceptual knowledge and procedural knowledge tend to produce a positive effect on an individual's self-efficiency when it comes to avoiding phishing scams.

PicoCTF

A new and innovative competition has emerged among high school computer science enthusiasts, called PicoCTF (Chapman et al. 2014). Unlike conventional computer games, this competition is aiming to broaden the student's understanding of computer security, through a series of web-based game challenges. PictoCTF is based on the idea of capturing the flag. Teams race to solve computer security obstacles, looking for a digital "flag," encrypted in text or a binary program and saved in an unknown server. Although the competition can last for a couple of days for a team to win by discovering the exact location of the flag, the many challenges faced by the competitors and the array of solution they come up with will allow them to learn crucial skills in computer forensics, cryptography, web security, reverse engineering, and binary exploitation. This game is both an entertaining, challenging yet legal way for both students and tactically professional experts to practice and improve their skill in a computer breach, which in turn will give them a better understanding of how breaches can happen and how to avoid them.

Control-Alt-Hack

Meanwhile, Control-Alt-Hack is a new design of card game also aiming at increasing awareness of computer security by changing people's understanding and discipline (Denning et al. 2013). The players of the game simulate the employees of Hackers Inc., which is a tech security company that performs advanced checks on the security of individuals by actively trying to hack it and then provide consultation services to the individual on whom to improve their security. For the evaluation of the game, a group of 22 educators and 250 students were taking into account. Most of the educators indicated that the game was a great teaching tool, in that they would use it again, as it was greatly welcomed and enjoyed by the students, while it significantly increased their understanding of computer security. Therefore, some educators believed that they would even recommend it to others. A secondary supplementary evaluation of 11 educators teaching nonsecurity computer science courses showed that their response similarly aligned with a larger group, with some reporting that they would no longer teach any computer science course with the game.

Conclusion

In this article, the authors discussed and referenced briefly phishing attacks focusing on gamification which is actually social engineering. Then they categorized the existing strategies to tackle the issue and enhance the awareness of users regarding the gamification solutions. Phishing manipulates individuals psychologically to reveal confidential information. Phishing is a common form of identity theft and is considered a serious and server cybercrime. The most common phishing uses emails, chats or websites, and online games to get valuable information. Education and training in the case of gaming have become very essential even for a common man to prevent phishing. In order to handle phishing in gaming, some of the existing methods have been discussed. Since organizations are emphasizing the education and training of their employees for data protection, game-based learning is one of the top methods to identify phishing attacks.

Cross-References

► Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features

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Anti-social Behavior

► Griefing in MMORPGs

AnvilNext

► Assassin's Creed, an Analysis

Any%

► Speedrunning in Video Games

AODV

► Simulation and Comparison of AODV and DSDV Protocols in MANETs

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Area of Interest

► Area of Interest Management in Massively Multiplayer Online Games

Area of Interest Management in Massively Multiplayer Online Games

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Synonyms

AOI; Area of interest

Definition

In a Massively Multiplayer Online Game, the Area-Of-Interest (AOI) is that portion of the virtual world of specific interest for a player.

Introduction

Users participating in a Massively Multiplayer Online Game (MMOG) share a synchronous and persistent virtual world with each other through Avatars, i.e., the players alter ego in the virtual world. In order to enable an engaging experience

typical of MMOG, the state of entities in the virtual world, such as avatars and objects, has to be replicated in avatar nodes in a timely fashion. However, broadcasting all state changes to every node in a MMOG is not a practical solution. Naturally, each avatar is interested to be updated in only a subset of the whole virtual world, which is commonly referred to as Area of Interest (AOI). The AOI management (AOIM), often referred to also as Interest Management (2002), is a core activity in the operations of a MMOG, and can be informally defined as the following: given an avatar, identify its AOI and activate those operations that support its timely update. AOIM is also referred to as spatial publish subscribe (Hu and Chen 2011). In this model, publishers perform action and interact with the virtual world (e.g., perform some movements), whilst subscribers manifest their interest of receiving updates for a specific area of the virtual world. AOIM is a fundamental operation in both centralized and distributed MMOG architecture. In the centralized ones, it is principally a mean to reduce the volume of messages exchanged by the client and the server, as well as the amount of data stored and elaborated locally to the client. In distributed MMOG architectures instead, how AOIM is performed greatly impacts on the whole architecture. In fact, AOIM often drives the design of the whole decentralized architecture, forcing an organization of the connections between nodes so that they are only communicating with other nodes that have relevant entities. AOIM can be divided into two main categories (Carter et al. 2012): spatial and geographic.

Spatial AOIM

Spatial AOIM is based on the concepts of aura and nimbus (Boulanger et al. 2006). The aura is the spatial area for which an entity is perceived by others, whilst the nimbus is the spatial area for which an entity can perceive. Hence, an entity A can perceive another entity B only if A's nimbus intersects with B's aura. However, in this case, B is not necessarily aware of A (i.e., the relation is not mutual). In practical implementations, however, aura and nimbus coincide in a circle (or a sphere) with a predefined radius and centered on the avatar. In such case, the circle is simple referred to as AOI, and the awareness is mutual such that if A is aware of B, B is also aware of A. Spatial-based AOIM mechanisms can employ a static and persistent implementation of the AOIs (Carlini et al. 2012), or dynamic, by adjusting the AOI shape and size according to the events happening in the virtual world (Ahmed and Shirmohammadi 2008).

Geographic AOIM

Geographical AOIM exploits the subdivision of the virtual world into regions, which are then distributed to different servers. Geographical and spatial AOIM are often used in combination: the spatial AOIM is used to select those, among the regions provided by the geographical AOIM, that are of interest for the avatars. A coarse grained geographical AOIM is usually implemented by large centralized MMOG by dividing the virtual world into large regions and instances (Prodan and Nae 2009). Normally, the nimbus of avatars is much smaller than such regions, and therefore only one region (i.e., server) is selected, as typical of centralized approaches.

More fine grained subdivisions of the virtual world are typical of decentralized MMOG architectures (Ricci and Carlini 2012). A common approach considers an uniform partitioning of the virtual world into rectangles or hexagons, with the area of interest that can span more regions. Static uniform partitioning approaches have the problem of properly defining the region size. If the size is too large, an avatar could receive state updates from entities not in its actual interest, wasting resources. Otherwise, if the region is too small, an avatar would need to manage multiple region of interests and switch very frequently between them, generating a lot of overhead. In order to overcome these problems, in dynamic partitioning, the size of the region can be optimized according to various parameters, such as the number of avatars in a region, or the computational power of the node managing a region (Deng and Lau 2014). An evolution of the dynamic partitioning approach is the hierarchical partitioning, which is usually implemented by considering tree-like structures, such as QuadTrees (Backhaus and Krause 2010). An advantage of this method is that the size of the

regions can be abstracted at the correct level by simply navigating the tree structure. A special instance of geographical AOIM is the one based on Voronoi tessellation (Hu et al. 2006). A Voronoi tessellation is a decomposition of a metric space determined by the distances from a set of sites (usually determined by the position of the Avatar) of a discrete set of objects in the space. Given a set of N sites on a two-dimensional euclidean plane, the plane is partitioned into N nonoverlapping regions, each one containing all the points closer to that region site than to any other one. Voronoi-based AOIM approaches, and the corresponding Delaunay triangulation (Ricci et al. 2015), are especially used in decentralized MMOG architectures as they facilitate the task of connecting neighbors with P2P mechanisms. In general, the Voronoi tessellation is dynamically computed by considering the positions of the avatars, then a peer-to-peer communication overlay is defined by connecting two peers managing avatars whose Voronoi regions share at least an edge (i.e., are neighbors) (Ricci et al. 2013).

Cross-References

► Interaction

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Area of Interest, AOI

► Peer-to-Peer Gaming

Artificial Cognitive Intelligence

► Computer Games and Artificial Intelligence

Artificial Intelligence

► Genetic Algorithm (GA)-Based NPC Making
► Foundations of Interaction in the Virtual Reality Medium
► Human Interaction in Machine Learning (ML)

for Healthcare
▶ RTS AI Problems and Techniques
▶ StarCraft Bots and Competitions

Artificial Intelligence Agent

▶ Assassin's Creed, an Analysis

Artificial Reality

▶ Origin of Virtual Reality

Artificial Reality Continuum

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Synonms

Augmented reality; Extended reality spectrum

Definition

The Artificial Reality Continuum (ARC) describes the spectrum of technologies that augment or replace the natural sensory stimuli: vision, hearing, touch, smell, or taste. On one side of the spectrum is the reality itself, as perceived with our own senses without artificial augmentation. On the other side of the spectrum is the virtual reality, where sensory stimuli are entirely artificially generated. In between the reality and virtual reality, the degree of augmentation, extension, or replacement of natural sensory stimuli varies.

Introduction

The ARC is always tied to a human user Scholz and Smith (2016); Dirin and Laine (2018). It cannot exist without a human being because it is just an experience. It is possible for many humans to view and interact with the same artificial reality (Kaufmann (2003); Pidel and Ackermann (2020)). Recently, collaborative artificial reality applications are commonly referred to as the *Metaverse* Mystakidis (2022). Generally, the artificial reality continuum is a virtual concept and is experienced through the visual sense of a human. Besides vision, the hearing sense also plays a secondary important role. Through sound, the level of immersiveness of the artificial reality experience is increased. In some cases, the visual artificial reality gets extended and stimulates the other human senses touch, taste, and smell.

The disciples in the ARC are Augmented Reality, Mixed Reality, and Virtual Reality. It is also important to define the boundaries of the ARC. An important factor is the degree of visual immersiveness and interaction with the environment. A traditional theater experience can be physiologically immersive. People's emotion change because they feel with the characters. Yet, the acting takes place in reality and is therefore not considered artificial reality. Sitting and watching in a movie theater can be immersive, and the reality that is shown on the screen is artificial, but still this is not considered artificial reality because there is no active interaction between the movie and the environment the viewer is in.

The ARC was defined from a device perspective by Milgram et al. (1994). They create a taxonomy that divides the ARC in three dimensions: reality, immersion, and directness. The three axes refer to the extent of world knowledge, reproduction fidelity, and extent of presence metaphor. Skarbez et al. (2021) adapted the taxonomy by Milgram et al. (1994) and introduced the three dimensions' extent of world knowledge, immersion, and coherence. This work analyses the ARC from a user experience and application perspective focusing on current technological capabilities with current devices. Moreover, we define Mixed

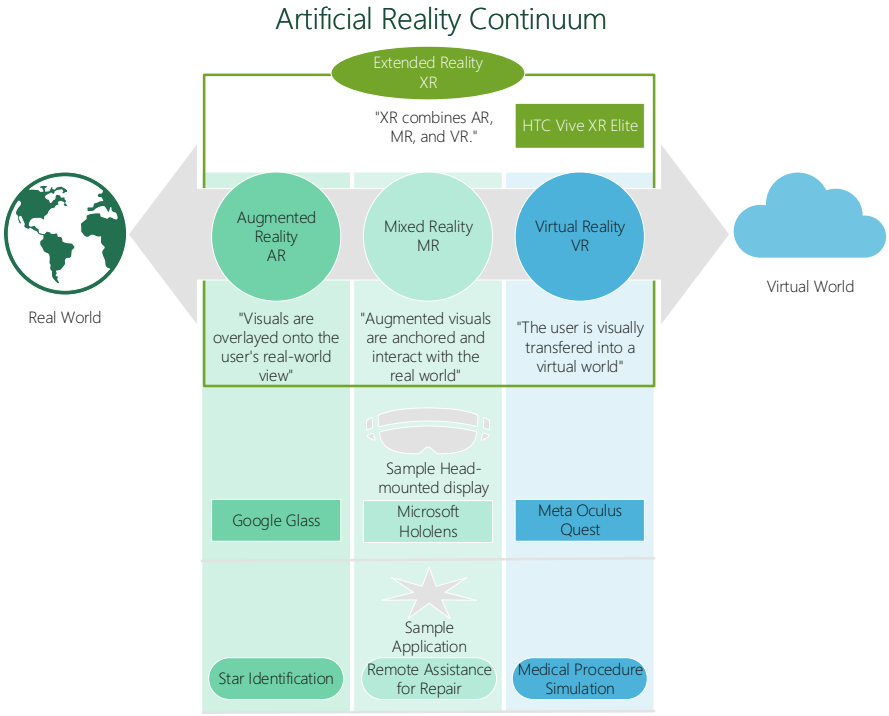
Reality (MR) as a stage between Augmented Reality (AR) and Virtual Reality (VR) rather than an umbrella term describing the whole spectrum. Instead, Extended Reality (XR) includes AR, MR, and VR. An overview of how the ARC is presented in this work is shown in Fig. 1.

Disciplines Within the Artificial Reality Continuum

People start to talk about the artificial reality continuum as soon as the information that is visually displayed depends on the environment the user is in. In all forms of artificial reality, the awareness between virtual and reality goes only in one direction. From the real environment to the virtual environment. The interaction can never happen in the opposite direction because this would mean that reality changes directly from the influence of the virtual reality (VR) which is physically not possible. However, the user can act as a bridge between virtual and real environment. Indirectly the virtual environment can influence the real environment. For example, the virtual environment can tell the user how to perform a certain operation in the real environment. Examples include remote maintenance (Mourtzis et al. 2020), and health-care assistance (Rebol et al. 2022). Once the user performed the instructions visualized in the virtual environment, they indirectly changed the real environment.

Augmented Reality

In augmented reality (AR), the information flow between the virtual and the real environment goes only from the real to the virtual environment. The real environment gets extended with visual and auditory information (Reipschlager et al. 2021). In some AR applications, the physical environment influences how the virtual world is rendered. However, this is not a requirement for AR. Some AR applications scan the physical environment to provide anchored augmentations depending on which real environment the user sees. This allows for predefined visualizations to get displayed on



Artificial Reality Continuum, Fig. 1 An overview of the Artificial Reality Continuum (ARC)

top of reality. Augmented reality is not designed to change the real environment. The boundary between augmented reality and mixed reality is at the point where the augmented information tries to influence the real environment. The sole purpose of augmented reality is to enrich reality by providing additional visualizations.

In museums, AR is used to provide text descriptions and animations for exhibits (Ding et al. 2017). In books, AR is used to extend traditional 2D illustrations with 3D AR scenes (Dünser et al. 2012). Interactivity does not take place with the AR objects itself. Only small changes in the virtual environment are possible such as changing the position where the virtual elements appear. Pokemon Go pok (2022) is the most famous AR game. Besides the entertainment applications, AR is also used in heads-up displays in air crafts and vehicles (Jose et al. 2016). The virtual elements in the game (Pokemon) appear augmented through a screen on the real world. Augmented reality devices are displays of phones and tables, projectors, and glasses with integrated see-through displays.

Mixed Reality

In contrast to augmented reality, mixed reality (MR) not only enriches the real environment by displaying visualizations for the user but also makes the user interact with the environment. The virtual environment changes the real environment with the help of the user. The interaction must include the physical environment and can also take place in the virtual world. MR headsets that support hand tracking allow the user to intuitively alter the virtual world. Moreover, in every mixed reality application the virtual environment is fully aware of the real environment. Mixed reality is the most complex technology because it tries to create a new seamlessly combined reality. In AR, the attention is on the real environment and the augmentations just enrich the reality. In virtual reality, the attention is on the virtual environment and the user is not visually aware of the real environment. In MR, the attention switches between the real and the virtual environment.

Mixed reality creates a cooperative scene which can be used for virtual meetings and collaboration. Virtual objects are used to explain concepts in the real environment. One person can guide another person if the mixed reality views are transferred over the Internet (Rebol et al. (2022); Mourtzis et al. (2020)). One person can give direction using virtual objects on the other side. The person that receives the direction through mixed reality can work based on the directions received. In industries, mixed reality is often used in cases where a remote expert guides a local operator (Rebol et al. 2022). Traditional 2D video guidance is sometimes not practical because the complexity of the problem requires spatial information. In the logistics industry, special machines are deployed in warehouses (Mourtzis et al. 2020). Only few experts are able to fix the machines whenever they stop working. In order to repair machines efficiently, a remote expert guides a local mechanic through the procedure with MR. The remote expert would otherwise need to travel long distances to fix the problem which would take more time and cost would be high.

Virtual Reality

Virtual reality (VR) tries to completely detach the user from reality and take the user to an all virtual environment (Auda et al. 2020). Although the user keeps physically in the real world, virtual reality creates the impression that the user enters a new virtual world. Compared to augmented and mixed reality, the user does not see anything from the real environment, except for themselves in cave automatic virtual environment (CAVE) experiences (Muhanna 2015). Most of the time, the visual experience is also paired with audio and the user wears headphones which makes the user hear sounds from the virtual environment. Modern virtual reality devices are displays mounted very close to the user's eyes to cover the real environment. They are head-mounted displays (HMDs) consisting of the display, headphones, microphone, and sensors to track the user's motion. In order to make the virtual experience of Artificial Reality Continuum 5 as realistic as possible, the motion of the user is tracked and transferred to motion in the virtual environment. VR device tracking ranges from head tracking only to full body tracking.

Similar to mixed reality, virtual reality is used for virtual meetings and collaboration. Distant people can meet in the virtual world to discuss work in the real world or work together on virtual tasks. People see each other as represented as avatars in the VR. The degree of avatar detail and realism changes. The degree of avatar realism has an influence on the perception in VR Latoschik et al. (2017). More abstract avatar representations require less computing power. Realistic representations can be retrieved by a volumetric capture of a person (Yu et al. 2021). However, in combination with realistic capture, precise motion tracking and mesh deformations are required to reach a high degree of realism.

One difference between virtual reality and augmented and mixed reality is the fact that it is completely detached from the real environment. Therefore, the user can be taken into a completely new world which the user would not be able to experience in reality. It can be a place on real world that is somehow unreachable for the user such as the cockpit of a rocket or distant vacation destination. It can also be a completely fantasy place. This allows for the application to simulate situations and train people. Examples include fire rescue, medical training, and pilot training. By combining a visual VR experience with additional realism such as sound, haptic feedback, environment motion, and smell, a highly realistic scene is created. The user's body is physically moved according to the visual VR experience.

The Continuum

The transition between AR and MR is seamless. MR applications include AR. AR and MR can be distinguished by the sensors the display device is using. In AR, there exist two types of augmentation. The most simple version of AR augments information onto a display without taking the real environment into account. One example for this is a heads-up display in a car that projects cruising information such as speed and direction onto the windshield (Jose et al. 2016). Another example would be wearable see-through glasses that project the current time and weather information into the field of sight of the user. This information is projected regardless of the environment the user is currently in. Those devices only need a projecting display. They do not need sensor to scan the environment.

The more sophisticated version of AR is partially aware of its environment. This version of AR scans the environment and searches for predefined elements on which information is augmented. For example, in an AR book (Dünser et al. 2012), the AR device is searched for illustrations or markers. Whenever something is detected, the corresponding visual information is overlaid for the user. This detection requires additional sensors for the AR device. Mostly, these types of AR devices contain a display and a color camera. Devices are mainly phones, tablets, and glasses. The color camera captures the real scene and applies image recognition algorithms to detect given objects in the scene. Consequently, these types of AR devices require more computations resources compared to the most simple form of AR. Despite recognition, tracking is performed to stabilize augmentations when the user moves the AR device. The tracking makes this type of AR more enjoyable than simple AR displays. It makes the virtual and the real environment merge and the experience for the user is better because the user does not need to switch visually between the decoupled virtual and real environment. Accurate tracking is an important factor for a smooth AR experience. Slow or inaccurate tracking results in high cognitive load for the user and can result in motion sickness (Kaufeld et al. 2022).

Mixed reality is very closely related to the more sophisticated version of AR described above. The main difference is that in mixed reality the awareness of the real environment is even higher when creating the virtual environment. Therefore, MR devices have more sensors than AR devices. They spatially capture the surroundings the user is in. A depth sensor, a stereo camera setup, or laser-based systems are used to capture the 3D scene. In order to process this information, more computations resources are required compared to AR devices. Typical MR devices include phones which 3D capture capabilities and head-mounted displays.

In MR, device tracking becomes an important part because all the virtual objects are linked to the

real objects and need to stay at the same position. On head-mounted displays, the motion of the user's head needs to be tracked (Sathyanarayana et al. 2020). On phones, the position of the device needs to be tracked. Especially with head-mounted displays presenting a high portion of virtual environment, motion sickness (Kaufeld et al. 2022) becomes a concern, and therefore accurate head-tracking becomes essential. Even with a low degree of virtual environment, head-tracking needs to be accurate in order to decrease cognitive load and to support seamless integration of the virtual and the real environment. To allow for accurate tracking of user motion, the data from multiple sensors inside the MR device are utilized, including depth sensors, multiple RGB cameras, accelerometer, and gyroscope.

Mixed reality applications typically do contain AR elements that are not aware of the real environment and are visualized on a fixed screen position. These elements are typically application menus that are used frequently by the user and therefore need to be close. Mixed reality applications have the option to guide the user to engage not only with the virtual environment, but also with the real environment. Thus, MR is the preferred discipline within the artificial reality continuum for effective remote collaboration.

Although MR applications with a high portion of virtual elements come close the virtual reality experience, the concept of VR is substantially different from that of AR and MR. The user drifts completely into the virtual world. VR devices are designed such that they block the sight of the real environment. VR is predominantly consumed with a head-mounted display which blocks any light coming from the real environment to the user's eyes. A very high immersiveness factor within the artificial reality continuum is reached when VR does not only use the visual sense to bring the user into the virtual world. The real environment might react corresponding to the virtual environment to simulate motion and touch.

Applications of Artificial Reality

The artificial reality continuum is present in video games as well as other applications (Das et al. (2017); Solbiati et al. (2020)). The most famous AR Game is Pokemon Go. The most popular AR application outside gaming is the heads-up display in cars. Mixed reality applications are not widely spread. They are mainly used for commercial and research purposes (Rebol et al. 2022). MR is used for remote assistance, for example, special machine maintenance (Mourtzis et al. 2020). It is also used in medicine for 3D visualization of recorded volumetric data on patients. Virtual reality is much more popular than MR. Especially the gaming industry uses VR head-mounted displays to create immersive gaming experiences. The movie industry has produced documentaries in VR.

One obstacle toward the broader adoption of the ARC is the lack of standardization of devices. AR, MR, and VR devices are designed with different sensors and capabilities which makes cross-platform development difficult. Standardized application development between different mobile devices, head-mounted displays, and other ARC devices needs to be introduced. The type of sensors on devices needs to provide standardized capabilities such as device tracking and remote connection.

Interaction in the Artificial Reality Continuum

The interaction with the ARC depends on the device. Modern mobile devices including phones and tables offer interaction with AR capabilities. They 3D scan the environment with a multi-camera setup and support AR and MR applications. Phone displays offer low-entry VR support with additional head-mounted hardware. AR applications for mobile phones are popular because of the wide availability of the hardware. The fact that the display needs to be carried makes mobile phones a less suitable device for ARC applications. Moreover, state-of-the-art phones do not offer stereoscopic display capabilities. Consequently, only 2D views are supported.

In contrast to phones, glasses and lenses offer 3D visualization and are easier to carry. The

display and the computing unit need to be separated on these devices for comfortable usage. Glasses and lenses offer a much more intuitive way of consuming ARC content. When using mobile device, the interaction can happen through traditional touchscreen controls but can also happen through more intuitive in-the-air gestures. Gestures are detected using integrated hand pose estimation algorithms which are less accurate than touchscreen controls. On head-mounted displays, interaction is possible with gestures. Integrated depth cameras can ensure high precision such that the interaction with virtual objects feels similar to interaction with physical objects.

Within the ARC, augmented reality does not support interaction. Mixed reality applications require spatial scene understanding to allow for interaction with both physical and virtual objects in a natural way. Natural interaction happens through user gesture control. Hence, gesture detection is built in. In VR, gestures are detected with controllers or stereo cameras. Besides gestures, voice recognition is used for communication in a virtual environment. The disadvantage of gesture recognition with controllers is that the user has to hold a physical object which is less natural than gesture recognition with cameras. Gesture recognition with separate static hand-tracking devices is feasible put limits the area of interaction and is therefore mainly suitable for VR.

Conclusion

The artificial reality continuum offers different ways for the user to interact with virtual content: augmented reality, mixed reality, and virtual reality. Current consumer products come from both ends of the spectrum which are augmented reality and virtual reality. Especially for productivity and collaboration, mixed reality plays an important role. It is widely adopted in industry and is on the way to enter consumer markets.

Head-mounted displays combined with human user tracking offer the most intuitive technology to experience the artificial reality continuum. In the future head-mounted devices will have to become handier and part of people's everyday life.

Cross-References

▶ Tabletop Storytelling

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Artistic Data Visualization in the Making

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Synonyms

Artistic visualization; Data visualization

Definition

Artistic data visualization is visualization of data done by artists with the intent of expressing a point of view.

Introduction

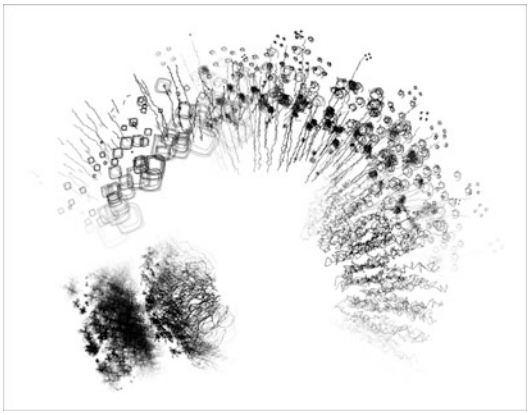
In recent years, we have seen an increasing of interest in data visualization in the artistic community. Many data-oriented artworks use sophisticated visualization techniques to express point of views or achieve persuasive goals. Meanwhile the attitude that visualizations can be used to persuade as well as analyze has been embraced by more people in the information visualization community.

Here I will share my experience and reflection in creating data visualization as artwork via case study of two recent projects. It presents a workflow from conceptual development, data analysis, to algorithm development, procedural modeling, and then final image production. It hopes to offer insight into the artist's effort of finding balance between persuasive goals and

analytic tasks. Furthermore, it raises the question of the roles of artistic data visualization played in assisting people to comprehend data and the influence of this artistic exploration in visualization might have injected in shifting public opinions.

Case Study: Out of Statistics: Beyond Legal

This project produces a series of 52 abstract drawings based on US crime statistics as digital prints on rice paper and silk panels. Each image represents the crime status in one of the states, with the seven most significant crime-conviction statistics of each state embedded.

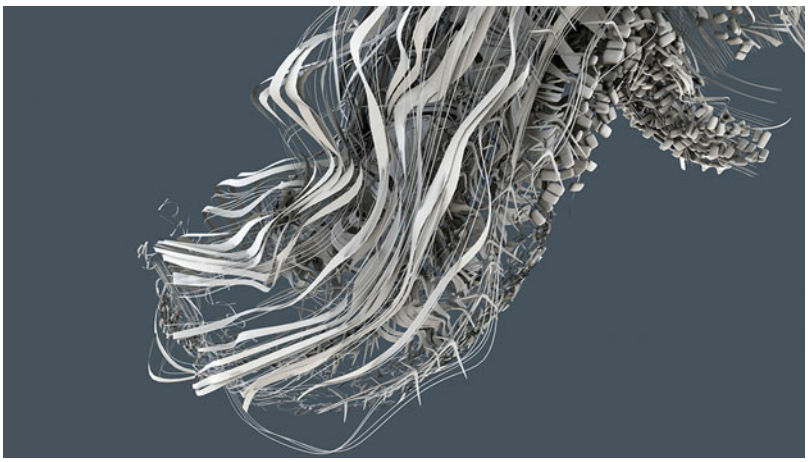


Case Study: Perpetual Flow

This project explores an aesthetic-oriented approach to visualizing federal spending in the United States as 3D compositions in a photo-realistic style. Using procedural modeling with Python programming and Maya API, an organic flow of intermingled geometrical units is formed to represent the profile of federal spending for each state, loosely resembling the idea of money flow. The total amount of spending is scaled to a per capita basis to make different states comparable, while the overall surface area or volume occupied by each type of geometrical pattern represents its associated spending data (Xu and Zhai 2013).

Biography

Rebecca Ruige Xu currently teaches computer art and animation as an Associate Professor in College of Visual and Performing Arts at Syracuse University. Her artwork and research interests include experimental animation, visual music, artistic data visualization, interactive installations, digital performance, and virtual reality. Her recent work has been appeared at Ars Electronica; SIGGRAPH Art Gallery; Museum



of Contemporary Art, Italy; Aesthetica Short Film Festival, UK; CYNETart, Germany; International Digital Art Exhibition, China; Los Angeles Center for Digital Art; Boston Cyberarts Festival. She has also been a research fellow at Transactional Records Access Clearinghouse, Syracuse University since 2011.

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Artistic Visualization

▶ Artistic Data Visualization in the Making

Assassin's Creed

▶ Assassin's Creed, an Analysis

Assassin's Creed, an Analysis

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Synonyms

Action-adventure game; AnvilNext; Artificial intelligence agent; Assassin's Creed

Definition

Action-adventure game	A game with a mix of elements from an action game and an adventure game
Action game	A game that requires physical skills and challenges such as hand–eye coordination and reaction time
Adventure game	An interactive story driven by exploration, dialogues, and puzzle-solving
Artificial intelligence agent	An automated agent that performs tasks by mimicking some levels of human intelligence
AnvilNext	A game engine created in 2007 by Ubisoft Montreal video game developers for use on Microsoft Windows, Nintendo Switch, PlayStation 3, PlayStation 4, PlayStation Vita, Wii U, Xbox 360, and Xbox One

Abstract

Assassin's Creed is an action-adventure video game franchise created by Patrice Désilets, Jade Raymond, and Corey May, developed and published by Ubisoft using the game engine AnvilNext. Coded mainly in C++ and C#, Anvil is a game engine created in 2007 by Ubisoft Montreal for use on Microsoft Windows, Nintendo Switch, PlayStation 3, PlayStation 4, PlayStation Vita, Wii U, Xbox 360, and Xbox One.

Assassin's Creed IV: Black Flag

Have you even wondered what it would be like to be a pirate in the middle of the Caribbean during the height of pirating? Well, look no further than the awesome sequel to the Assassin's Creed Series: Assassin's Creed IV – Black Flag. The Ubisoft company, specifically the Ubisoft Montreal office, made every effort to make sure this game was a blockbuster on its release back on the 29 October of 2013, to include utilizing the advanced AnvilNext Engine for the Xbox 360 release. The game was during its time one of the most advanced action-adventure/stealth games of that year with an initial

release on Xbox 360, PlayStation 3, and Wii U; it was later patched over to the PlayStation 4, Xbox One, and Microsoft Windows after the release of the next-gen consoles on 22 November 2013. This gory single-player/multiplayer will have you sitting on the edge of your seat, taking full advantage of the ESRB rating of M for Mature.

The game's main target audience was young adults between the ages of 18 and 25. The story was an easy hook for people who are fans of the series or not. Being a ship hand named Edward Kenway during the 1700s in the Caribbean who turns pirate to earn fortune has a brief run in with an assassin captain of an enemy vessel, whom Edward kills and steals his gear to impersonate a captain of a ship without realizing the uniform has other ties besides just the title of "Captain." With the gear he is consistently being pursued by an organization called the Templars who are seeking a device in the Caribbean and the Assassin's Brotherhood who seek him out for assistance in stopping the Templars. This game is so appealing not just due to the awesome aspects of pirating but also due to doing it during the greatest age of pirating! Plus, this series has a long working story arc over many games when it comes to the "present-day" story portion.

Games Mechanics

The games mechanics were unique even for this series. Each game in the Assassin's Creed franchise has brought a little something new to improve on the previous game, but they are usually minor like a slight adjustment to the combat mechanics or the ability to parkour (wall climb) up and down with a simplified button combo than in the previous game. In Black Flag however, they broke the mold of Assassin's Creed.

Assassin's Creed has been well known since the first game for its large landscapes, big maps, and the use of the parkour system to navigate the map in literally three dimensions. With that said, Black Flag had the largest map ranging everywhere south of the tip of Florida to Jamaica as shown in the following picture:

With this large map, most players would be daunted to think about the number of load screens that would have to go through every time they made a move toward one place or the other. The load time is a little above average, with approximately a 1–2 min load screen just to get into the game, but once you are in, you are in a completely open world with only two exceptions. The first being story cut scenes which is a given, but they flow well and do not have a load screen to prompt them. The other being the quintessential "Fast Travel" locations in game, which do have a load screen, but it is dramatically reduced compared to the opening screen, with only about a 30 s load time.

If you are thinking a map this large, surely, you would speed all your time just using the fast travel points to get around. Wrong! You have a ship that can travel around this area at a reasonably quick pace. You can go from "driving" to "walking around" in character at a push of a button. The fluid ship to person back to ship interaction makes it really easy to travel because all you have to do is pull up next to an island you wish to visit, stop driving the ship, and just jump off the side to swim ashore (again no loading screen for visiting a new location in the map).

Artificial Intelligence Agent

Ubisoft did this mechanic due to another feature that they added into the game: a literal never-ending number of AI NPC ships that you can attack and loot or even take over by engaging in hand-to-hand combat while boarding the ship. These AI ships range from smaller ships which are easy to take out for the early game play to four "God" ships in hidden locations spread around the map which are near impossible to defeat unless you have your ship fully rigged with the best gear.

Storyline

The story is extremely in depth, with plenty of actual real-world locations to explore and dozens of historical figures from the Golden Age of Piracy to interact with. An example is Edward Teach who is better known as "Black Beard," the notorious English pirate who was a scourge of the American coast for many years before his death at the hands of sailors sponsored by the Governor of Virginia to capture or kill the pirate. Other big names from the day are Anne Bonny, Charles Vane, John Rackham better known as Calico Jack, and Benjamin Hornigold – all of whom are notorious pirates from that time.

Assassin's Creed IV: Black Flag's open-world concept with a free-flowing story and the option to ignore the story and just do pirating stuff has received great public reception and was generally held as vastly superior to its predecessor Assassin's Creed III. Two days after the game's release, IGN ranked Assassin's Creed IV: Black Flag as the second best game in the Assassin's Creed series, only behind Assassin's Creed II (Sliva 2013).

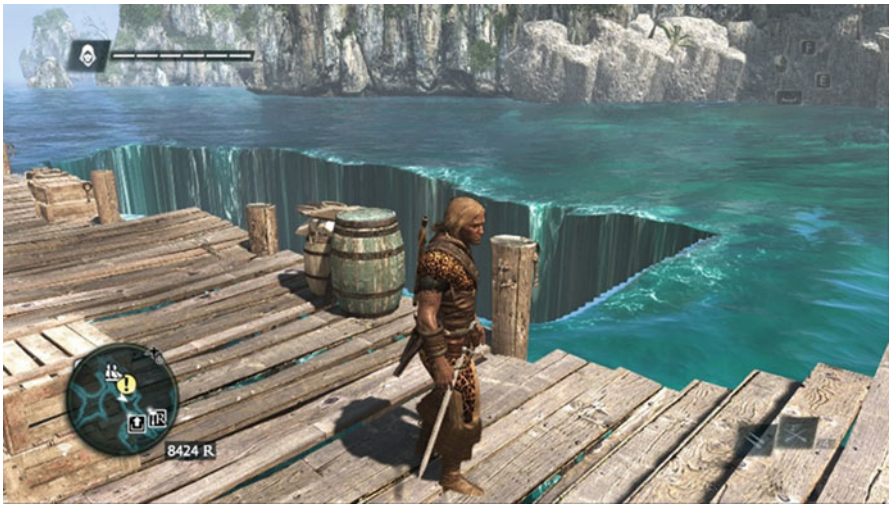
This game is perhaps the best game in the series by far. It has all the best features of the series with double story, open range action/adventure gameplay, and the awesome aspect of interacting with some of history's biggest names during the Golden Era of Pirates.

Controversy

The only controversy that popped up for this game is that PETA, the People for the Ethical Treatment of Animals, criticized the game for its usage of harpoons and the glorification of whaling. PETA also came out and said that it was disgraceful that the video game industry did not condemn it. Ubisoft's response was a statement saying that Assassin's Creed is based on history and it is a "work of fiction which depicts real events during the Golden Era of Pirates." Ubisoft also claimed they do not condone whaling, along with other mechanics and features in the fourth game in the series as shown in the following pictures:

Criticisms

The game was released only a month prior to a new generation of consoles coming out, and therefore it was built using an engine for the older generation of consoles (Xbox 360, PlayStation 3). When it was ported over to the new consoles (Xbox One, PlayStation 4), Ubisoft did not optimize the game for the better hardware in the newer



Assassin's Creed, an Analysis, Fig. 1 In the image, the large "hole" in the water is actually the player's ship resting in the water, but it is invisible to the player due to a software bug caused by the newer hardware

Assassin's Creed, an Analysis, Fig. 2 Assassin's Creed was released in 2007. You play as Desmond Miles in the modern story and as Altaïr Ibn-La'Ahad who lives during the Third Crusade in multiple locations in and around Jerusalem

consoles. As a result, many glitches happened when attempting to play the game on the newer consoles. In the image above, the large "hole" in the water is actually the player's ship resting in the water, but it is invisible to the player due to a software bug caused by the newer hardware.

Another major complaint from the gaming community is about the annual release of a new game. Ubisoft has been criticized for causing an oversaturation of the genre and a loss of innovation for the story arcs in each game.

Assassin's Creed, an Analysis, Fig. 3 Assassin's Creed II was released in 2009. You play as Desmond Miles again and as Ezio Auditore da Firenze during 1476–1499 centered around Florence, Italy

Assassin's Creed, an Analysis, Fig. 4 Assassin's Creed Brotherhood was released in 2010. You play as Desmond Miles again and as Ezio Auditore da Firenze during 1499–1507 centered around Rome, Italy

Evolution

The changes in each game in the series over the years have been minor. Comparing to the first Assassin's Creed on Xbox One S, the nine sequels to Assassin's Creed offer only minor improvements in graphics and audio.

The following series of pictures showcases the evolution from 2007 to 2018:

Assassin's Creed, an Analysis, Fig. 5 Assassin's Creed Revelations was released in 2011. You play as Desmond Miles again and as Ezio Auditore da Firenze during 1511–1512 Constantinople, Istanbul

Assassin's Creed, an Analysis, Fig. 6 Assassin's Creed III was released in 2012. You play as Desmond Miles again and as Ratonhnhakén:ton also known as Connor Kenway, who is a Native American turned assassin during the American Revolutionary War between the years 1765 and 1777

Assassin's Creed, an Analysis, Fig. 7 Assassin's Creed IV: Black Flag was released in 2013. You play as an unnamed employee of the company Abstergo during the modern story and as Edward Kenway during the Golden Era of Piracy between 1715 and 1722 in the Caribbean

Assassin's Creed, an Analysis, Fig. 8 Assassin's Creed Rouge released in 2014 was the final game designed for the Xbox 360 and PlayStation 3 generation of consoles but was later given a remastered edition for the new generation of consoles. You play as an unnamed Abstergo employee and as Shay Patrick Cormac who is an Assassin turned into a Templar (the assassin's rivals) during the 7 Years' War from 1756 to 1776 in the British colonies of North America

Assassin's Creed, an Analysis, Fig. 9 Assassin's Creed Unity released in 2014 was the first Assassin's Creed game created and released only for the new generation of consoles. It was also the first to incorporate a cooperative multiplayer in the story. You play as the "Initiate" who is a player of the Abstergo game called "Helix" and as Arno Dorian who is an assassin during the French 252 Revolution in 1789 and who goes to the Thermidorian Reaction in 1794 in Paris, France

Assassin's Creed, an Analysis, Fig. 10 Assassin's Creed Syndicate released in 2015 is the first Assassin's Creed to include two main characters that are played simultaneously in the memory segments of the gameplay to include the series' first playable female character. You play as the "Initiate" who has fully bought into the Assassin Brotherhood and is working for them in the present time, and during the past, you play as twins Jacob and Evie Frye during 1868 Victorian Era London, England

Assassin's Creed, an Analysis, Fig. 11 Assassin's Creed Origins was released in 2017. You play as Layla Hassan, a researcher at Abstergo's Historical Research Division during the present-day story, and as a Medjay named Bayek during 49–43 BC Ptolemaic, Egypt

Assassin's Creed, an Analysis, Fig. 12 Assassin's Creed Odyssey was released in 2018. The game takes place in Ancient Greece in the year 431 BCE during the fic tional Peloponnesian War between Athens and Sparta. You play as a male or female mercenary who fights for both sides

1. Assassin's Creed was released in 2007. You play as Desmond Miles in the modern story and as Altaïr Ibn-La'Ahad who lives during the Third Crusade in multiple locations in and around Jerusalem.
2. Assassin's Creed II was released in 2009. You play as Desmond Miles again and as Ezio

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4. Assassin's Creed Revelations was released in 2011. You play as Desmond Miles again and as Ezio Auditore da Firenze during 1511–1512 Constantinople, Istanbul.
5. Assassin's Creed III was released in 2012. You play as Desmond Miles again and as Ratonhnhakén:ton also known as Connor Kenway, who is a Native American turned assassin during the American Revolutionary War between the years 1765 and 1777.
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7. Assassin's Creed Rouge released in 2014 was the final game designed for the Xbox 360 and PlayStation 3 generation of consoles but was later given a remastered edition for the new generation of consoles. You play as an unnamed Abstergo employee and as Shay Patrick Cormac who is an Assassin turned into a Templar (the assassin's rivals) during the 7 Years' War from 1756 to 1776 in the British colonies of North America.
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11. Assassin's Creed Odyssey was released in 2018. The game takes place in Ancient Greece in the year 431 BCE during the fictional Peloponnesian War between Athens and Sparta. You play as a male or female mercenary who fights for both sides (Juba 2018).

Cross-References

▶ Multiplayer Games
▶ Video games

References

For a game series that spans 11 games between 2007 and 2018 for various gaming platforms, there are countless articles, magazines, blog posts, and online articles that talk excessively about this series: from IGN to The Game Informer Magazine published by Game Stop. This series has been in the spotlight and is still going strong in spite of the "dark times" of the original Assassin's Creed and the failure of Assassin's Creed Unity due to rushed game development. This game series continues to be at the forefront of the RPG arena due to extraordinary writing and storylines along with above average graphics and annual title releases from Ubisoft. Some of the outstanding references are:

Juba, J.: Assassin's creed odyssey. https://www.gameinformer.com/review/assassins-creed-odyssey/fighting-for-glory (2018)

Sliva, M.: Assassin's creed 4: black flag review. https://www.ign.com/articles/2013/10/29/assassins-creed-4-black-flag-review (2013)

Asset Creation

▶ 3D Game Asset Generation of Historical Architecture Through Photogrammetry
▶ Planetary Generation in Games

Assisted Healthcare

▶ Virtual Human for Assisted Healthcare: Application and Technology

Audio and Facial Recognition CAPTCHAs for Visually Impaired Users

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Synonyms

Accessibility; Biometric and facial recognition; CAPTCHA; Cyber security; Machine learning; Visual impairment

Definitions

CAPTCHA (Completely Automated Public Turing test to tell Computers and Humans Apart) is a security check software placed on websites as a means to allow to differentiate users from bots upon login (Jiang and Dogan 2015). Security is needed to ensure that bots cannot enter protected environments, such as those associated with games or purchases, in order to protect human users and companies alike from the impact of unwanted interference of all kinds, including financial, social, or otherwise (Fanelle et al. 2020). Accessibility is a measure of equity in access to sites and site information for people with a range of disabilities (Berton et al. 2020). The article refers to visually impaired users as inclusive of both legally blind users as well as those who have sight differences or deficiencies that prevent their equitable use of sites and site information.

Introduction

Because bots exist, there will always be a need for processes to protect sites and users from their interference (Fanelle et al. 2020). Even so, visual impairments require the installation of alternatives to standard visual CAPTCHAs, which include character-based and audio-based options. At the same time, these alterative CAPTCHA designs may not be as effective, easy to use, or timely as standard visual CAPTCHAs, based on these viability requirements, and the fact that audio CAPTCHAs in particular are easily hacked (Meutzner et al. 2015). This means that CAPTCHAs for visually impaired users can lack both accessibility and security.

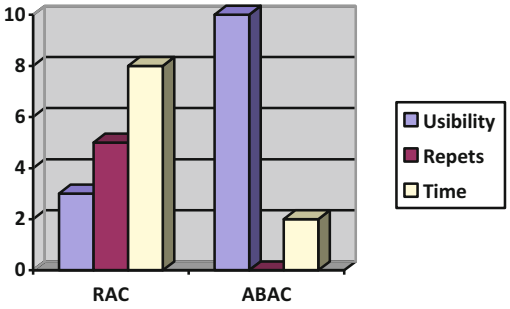
Our contributions in this paper are as the following:

- We have used advanced biometrics for facial recognition model in a real-time face detection.
- We proposed to use our impeded model for Webcam to improve the Audio CAPTCHAs.
- Finally, we are presenting the state-of-the-art accuracy for both facial recognition detection time and CAPTCHAs improvements for Visually Impaired Users.

Using Biometric for CAPTCHAS

The availability of alternatives to standard visual CAPTCHAs is limited. Biometric designs may be seen to be an easy solution to the issue (Noorjahan 2019), but the reality is that most visually impaired users engage in web-based sites through specialized equipment which may or may not be able to accommodate Fig. 1 provide some of the common equipment used for fingerprint, and they compared to the proposed method of using the actual key on the keyboard as an authenticated key. That would be as an option in the near term for using speech recognition instated of Audio CAPTCHAs (Fanelle et al. 2020). This means

Audio and Facial Recognition CAPTCHAs for Visually Impaired Users, Fig. 1 Type of biometrics is available for fingerprint



Audio and Facial Recognition CAPTCHAs for Visually Impaired Users, Fig. 2 Percentage of users for in the survey for each category of disability

Audio and Facial Recognition CAPTCHAs for Visually Impaired Users, Table 1 The characterized data of the participants were collected during our evaluation

Age	Number of participants	Visually impaired%
6–15	10	50
16–35	42	40
35+	11	80

that options that can take advantage of standard hardware, i.e., hardware that is used most frequently by visually impaired users, need to be prioritized (Alnfiai 2020). Whether standard hardware changes in the future or not, CAPTCHA options need to reflect what users prefer in order to meet accessibility and equity expectations (Berton et al. 2020).

Alternative CAPTCHAS for Visually Impaired Users

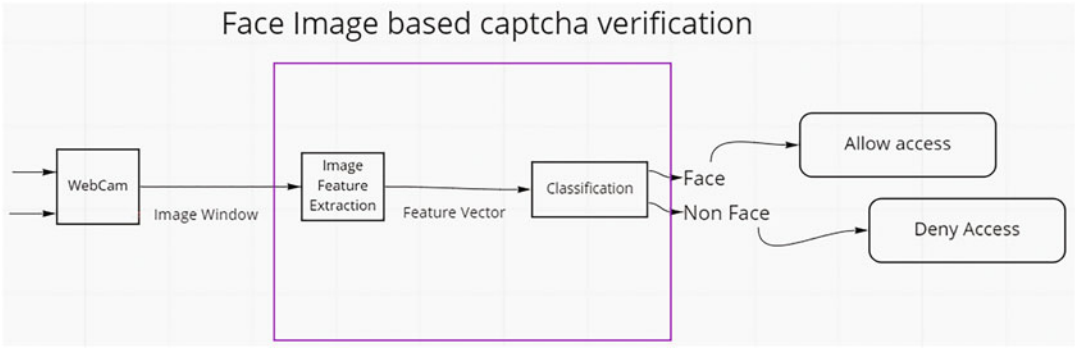
Given these needs, a number of alternative CAPTCHAs for visually impaired users have been tested in scholarly research in recent years and a number of factors that ought to be considered have been prioritized. The most ideal CAPTCHA is one that works for both sighted and visually impaired user with little to no differentiation, so that potential programming gaps are addressed (Alnfiai 2020; Shirali-Shahreza et al. 2013). This means that solutions need to be equally seamless for all users, and decrease extant time gaps for people with visual challenges (Alnfiai 2020; Fanelle et al. 2020). However, this is not always feasible, and most solutions need to work with existing web audio accessibility inputs such as Google reCAPTCHAs (Berton et al. 2020). CAPTCHAs that allow a user to swipe on a phone or handset when they hear a sound are likely to be successful (Alnfiai 2020). Having users reply using their own voices can be successful if security gaps are addressed by recombining CAPTCHA words in a control sequence that is connected with reCAPTCHA technologies (Jain et al. 2019).

Figure 2 shows the results of our comparison between Regular Audio CAPTCHAs (RAC) and our proposal Advanced Biometrics Audio CAPTCHA (ABAC). Table 1 presents overall data of the participants during the research.

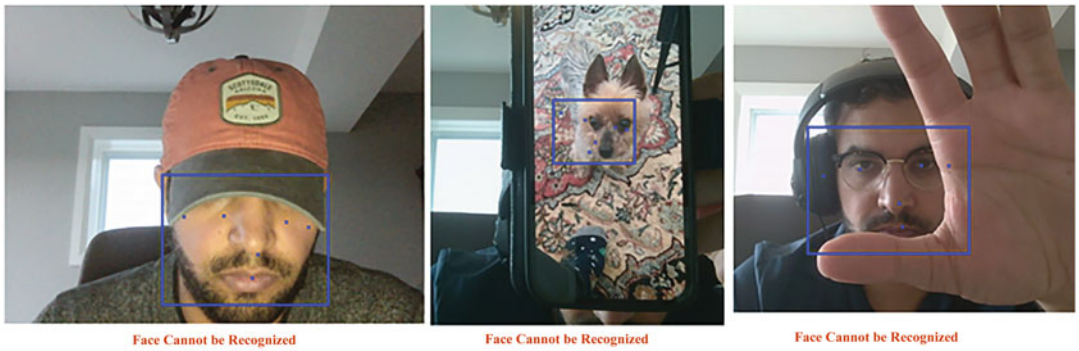
Our Proposal and Implementation

We currently use the deep learning-based facial recognition model called tiny face detection, built on the top of the single-shot shot detector (SSD) (Shafiee et al. 2017). Our deep learning model is made with the help of JavaScript programming, which helps us deploy the model over the web. After the model was built, we deployed the model over the web.

The main motive of our model is to detect if there is a human in front of the computer or not. So once the visually impaired person clicks the identify button, camera will open to determine if the person is present or not based on the facial recognition model. If a person is identified, then the captcha is a success and will go further if the camera fails to recognize the person. Then it says captcha is failed and ask's the user to try again. In



Audio and Facial Recognition CAPTCHAs for Visually Impaired Users, Fig. 3 Webcam model face recognition CAPTACHA



Audio and Facial Recognition CAPTCHAs for Visually Impaired Users, Fig. 4 Testing the accuracy of our model

Fig. 3 the architecture design for our proposed Webcam CAPTCHA.

This is the architecture of our deep learning model where initially, a person initiates the webcam, and then the feature extraction is done for every frame. Then it classifies whether based on the features extracted whether to allow or deny the access. The model will detect the face in a box for higher accuracy. Figure 4 shows defrent types of experiments we ran for testing our CAPTCHA.

Proposed Audio CAPTCHA Assistant

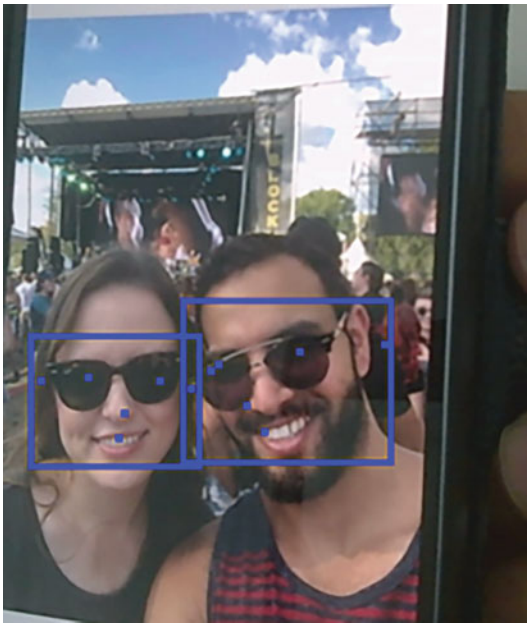
In our CAPTCHA, we have designed an audio assistant not only to provide speech to users but also provide guidance for visually impaired users. Instructions will be provided on how to best place the face for any visually impaired users on front of the webcam as shown in Fig. 4.

Limitations

There are certain limitations with our face detection model, such as our model is currently not able to distinguish between a photo and a normal person. In Fig. 5 the model will detect a face from picture where we intended to enhance the security to provide a real-time face detection with audio. The user will be able to hear the instructions for head adjustments, head rotation right, left, up, and down will eliminate any security issues we are facing from robots.

Conclusion and Future Work

For visually impaired users, alterative CAPTCHA designs may not be as effective, easy to use, or timely as standard visual CAPTCHAs. They may also lack security, especially if they are audio-based



Audio and Facial Recognition CAPTCHAs for Visually Impaired Users, Fig. 5 Our model detects the photo as a person and allows the captcha

alternatives. Nonetheless, new CAPTCHA options need to align to standard web protocols as well as standard hardware for visually impaired users and web browser accessibility requirements. This suggests that extra time is often the compromise that is made in designing CAPTCHA options that meet security and accessibility needs. Visually impaired users must spend extra time to get through a CAPTCHA sequence in comparison with standard users, which means that a truly equitable solution is lacking. Improvements to alternative CAPTCHA designs need to be created in order to ensure equity in the future, to avoid current pitfalls that create barriers to true security, accessibility, effectively and usability by introducing a real-time face detection CAPTCHAs.

Cross-References

- ▶ Accessibility of Virtual Reality for Persons with Disabilities
- ▶ Secure Gaming: Cheat-Resistant Protocols and Game History Validation

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Audio Collage

- ▶ Dynamic Music Generation: Audio Analysis-Synthesis Methods

Audio Description

- ▶ Visual Accessibility in Computer Games

Audio Design

▶ Sonic Interactions in Virtual Environments

Audio Game

▶ Audiogame

Audio Mosaicing

▶ Dynamic Music Generation: Audio Analysis-Synthesis Methods

Audiogame

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Synonyms

Audio game; Audio-only game

Definitions

An audiogame is a digital game that relies solely or primarily on audio output. Most audiogames can be played by both visually impaired and sighted players.

Introduction

While most digital games today heavily rely on sound in order to communicate information to the player, the role of audio in games is generally less significant than that of graphics (Collins and Kapralos 2012). Some digital games, however, invert this logic by either making graphics secondary to the audio or not using graphics at all, focusing on the sound instead. These are known as audiogames: games "fully playable by reliance on their audio output" (Karhulahti 2015).

For some game designers, stripping away the visual component of the game can be a way to experiment with the medium. *Dark Room Sex Game* (2008), a party rhythm game playable with the keyboard or Nintendo Wii's Wiimote controller, is one example, focusing on audio and haptic feedback to simulate sexual intercourse in a dark room (Oldenburg 2013).

More significant is audiogames' accessibility to visually impaired players, extending the reach of digital games beyond their traditionally assumed audience of sighted people (Friberg and Gärdenfors 2004). Online communities such as Audiogames.net have become hubs for visually impaired gamers, providing game reviews and publicizing events and competitions. The Game List section on Audiogames.net currently lists over 600 titles (most of them developed by hobbyists), though the list is not extensive and primarily focuses on English-language games.

History

Atari's *Touch Me* (1974), an arcade and handheld sequence memorization game, is considered to be a precursor to modern audiogames (Karhulahti 2015). While it did not exclusively rely on audio output (the sequence was duplicated as audio tones and light-emitted diodes lighting up), *Touch Me* could be played without using visual cues, although that would require the player to memorize the correspondence between the tones and the buttons first.

Audiogames for the personal computer became a possibility following the 1984 release of the original Apple Macintosh, which bundled with speech synthesis software *MacInTalk*. This enabled the Macintosh port of popular text adventure *Colossal Cave Adventure* to support voice output, making the game accessible to visually impaired users. Other text adventure games

followed, making the genre popular with the visually impaired gamer community.

The first notable commercial audiogame was *Real Sound: Kaze no Riguretto* (1997) developed by WARP Corp. for the Sega Saturn (Matsuo et al. 2016). It was conceived by game designer Kenji Eno after he learned of people with a visual disability who played his previous, visually intensive games by the ear. In terms of gameplay, *Real Sound* was an interactive radio drama where the player influenced the outcome of the story by choosing between several dialogue options at certain points within the game. While not a commercial success, *Real Sound* set an important precedent by being an audio-only game released by a major game publisher.

The 2010s have seen a rising number of audiogames appear: *Papa Sangre* (2010), *Sound Swallower* (2011), *The Nightjar* (2011), *Blindside* (2012), *Audio Defence: Zombie Arena* (2014), and many others (Beksa et al. 2015). The best-known of them, *Papa Sangre* (2010), is a survival horror game which takes place in a pitch-black dungeon, where sound positioning and reverberations provide the sole cues for navigation. Many contemporary audiogames, including *Papa Sangre*, are designed for tablets and smartphones; they also rely on touch controls, raising the question of their accessibility to players with a visual disability.

Some mobile audiogames, on the other hand, combine sound output with Braille writing to create a more accessible for visually impaired players while also helping them master Braille (Araújo et al. 2016). These games, however, may not be easily playable by sighted players who lack Braille literacy.

Design

On a basic level, there are several types of audio cues audiogames can rely on:

1. **Tone/pitch**: for example, Atari's *Touch Me* (1974) and *Simon* (1978), another memory game inspired by it, used sounds of a different pitch to identify the four key elements used to construct sequences for the player to memorize.
2. **Rhythm** and duration: rhythm games such as *PaRappa the Rapper* (1996) and *Beatmania* (1997) emphasize the timing of pressing the controls, and some subsequent games such as 2010's *Rock Band 3* can process actual music parts performed on a MIDI-enabled musical instrument.
3. **Spatial cues**: such games as *Papa Sangre* and *Blindside* focus on exploring invisible environments using sonic feedback such as reverberation.
4. **Narrative**: *Real Sound: Kaze no Riguretto* and the BBC's *The Inspection Chamber* (2017) rely on voice narration to communicate the story and use player choices as their core mechanic. Notably, *The Inspection Chamber* is controlled by voice input from the player instead of conventional controllers such as the keyboard.

It should be noted that many of the games mentioned above are not audiogames themselves; they just contain elements which can be used to construct one. These cues can also serve different functions: since audio output becomes the main vehicle for communicating information to the player, game sounds in audiogames need to fulfill a variety of roles, many of which are usually associated with game graphics. Friberg and Gärdenfors (2004), for example, divide sounds in audiogames into avatar, object, character, ornamental, and instruction sounds.

Various combinations of these types of cues and sound functions can be used to create a wide range of game dynamics, from role-playing games (Matsuo et al. 2016) to shooting games (Beksa et al. 2015) to platformers (Oren 2007) to puzzle games such as *Preludeamals* (2016).

Conclusion

While for most of their history, audiogames enjoyed little popular recognition, their recent resurgence, embodied by such titles as *Papa Sangre* and *The Inspection Chamber*, suggests

that they do yet have a potential for mainstream acceptance. This leaves hope for the reimagining of digital games as a medium that is accessible to sighted and non-sighted players alike.

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Audio-Only Game

► Audiogame

Auditory Impairment

► Computer Games for People with Disability

Augmented and Gamified Lives

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Synonyms

Augmented reality; Gamification; Serious games

Definition

Gamification uses game-based mechanics, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems (Kapp 2012). In this context, augmented reality (AR) as a popular technology can extend its functionality with the use of a camera and various sensors of a device to provide information with computer-generated methods.

Introduction

Nowadays, it is easier than ever to reach people in digital platforms, while the spread of COVID-19 is also forced the experts to find new methods to engage and support their students, clients, or participants in any field of life, but in a virtual format. This entry aims to provide a short conclusion about the key concepts and the actual trends in the field of gamification and augmented reality. After giving the definitions, examples of already existing, well-known, or innovative applications and research projects will be described to illustrate the most important takeaways about these fields. Gamification can be also applied to offline activities (Kermek 2019); however, the entry primarily focuses on a digital context.

Gamification and Serious Games

Gamification is a popular and widely used method to engage people and motivate the participants of

an in-person or digital activity. As its name suggests, the method was derived from the world of games, and it can be efficiently used in many different areas of our life, especially in the business sector and in the education. Of course, the design and the implementation depend on the actual use-case; thus, gamification has many similar, but different definitions. One of the most acceptable and abstract – thus use-case independent – definitions is Karl M. Kapp's one: *Gamification is using game-based mechanics, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems* (Kapp 2012). Gamification can be applied to any existing process, and the elements can engage the participants with their effect. However, the original process and the functionality must be retained; gamification can only be used to extend and improve them. On the other hand, the design and implementation of a serious game can be used for the same purposes, but the method clearly differs from the definition of gamification. In the context of a serious game, a brand-new activity is being designed with the experience of a game, but with a well-defined purpose and methodology. Thus, the development of a serious game differs from the core definition of gamification (see Fig. 1).

There are many examples of successfully gamified applications or successfully developed serious games, but there are many anti-patterns, of course. The most relevant keynote is that the elements of games should be used as motivation and to provide positive feedback; thus, the goals should be precisely designed, and the activity of the user should be controlled, while negative rewards and other feedback elements should be omitted. Thus, the success massively depends on the relationships between the different elements; thus, great gamified processes and serious games implement a bunch of elements. The set of implemented elements can depend on a specified user type for which an application is being developed (Ponick and Stuckenholz 2019). As in application development, various patterns can be discovered in gamified applications and the most common elements can be easily collected and divided into groups:

Augmented and Gamified Lives, Fig. 1 A serious game which aim is to provide an environment for practicing the built-in functions of spreadsheet software products

- *Activities* – Elements that offer activities and control the user such as missions, challenges, and goals.
- *Feedback* – Elements that give positive feedback to users such as scoreboards, progress bars, charts, experimental points (XPs), and experience levels.
- *Rewards* – Completions of activities should be rewarded with badges, experimental points (XPs), lifelines, privileges, and domain-specific items.
- *Sociality and interaction* – Users have profiles and can see each other's results in scoreboards, charts. They can compete in duels or special interactive activities.
- *Time* – This element always appears in a combination with another elements and is an important factor in the control of the user.
- *Design and modality* – Both in digital and in-person contexts, all the use of other elements depends on the user experience (UX) which is based on the design and the modality.

Augmented Reality

Augmented reality (AR) applications use the camera and various sensors of a device (typically cell phones, tablets) to enhance the visual experience with computer-generated perceptual information. In the last decade, a great number of AR applications have been developed in many different areas. AR is a preferred alternative to virtual reality (VR) because no additional devices (only the built-in ones) are required. Also, the latest mobile devices are designed with several additional cameras and sensors to improve the quality of their AR functions. The first well-known applications with AR functions were games, but the AR can be used in education, tourism, military, or for social purposes. According to a widely used library, AR functions can be divided into four main groups:

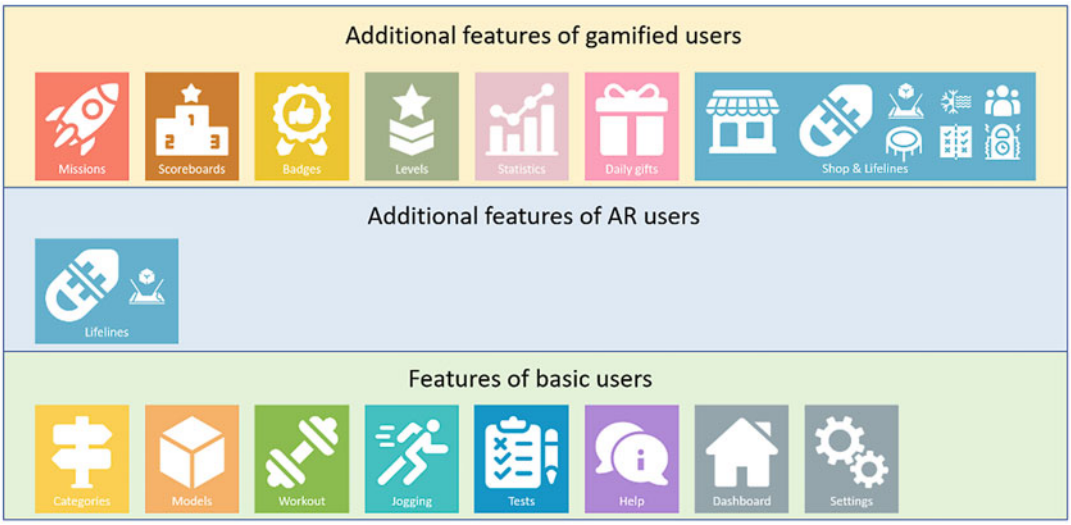
- *Instant placement* – This function scans for flat surfaces, then the users can instantiate 3D objects and place them on the detected surfaces. More interaction (such as scaling, moving the objects) can be achieved easily.
- *Cloud anchors* – This function is the extended and improved version of the instant placement in which multiple users can interact in the extended reality.
- *Augmented images* – This feature depends on a computer vision algorithm which simultaneously processes the picture of the camera and searches for features of specified images. With the use of this feature, users can instantiate 3D objects by scanning images.
- *Augmented faces* – This function is widely used in mobile operation systems, messaging applications and other gadgets. The face of the user is being detected with a computer vision algorithm and various objects can be put on them. After that, each movement of the user will be tracked by the sensors and the 3D objects will move in a synchronized way.

Concurrent Applications

It is clear that motivation is one of the most important factors in the success of a learning process. In the last decades, many platforms and educators have introduced gamification to engage their students. The most well-known language learning environment is one of the best examples for a carefully designed and precisely implemented gamified process (Huynh et al. 2018). It offers the basic mechanism of an online learning process – topics, exercises, notes, tests – but also engages its users with the friendly interface, social items, rewards, and time elements. Gamified elements can be discovered in loyalty programs of various companies, such as airlines (https://www.miles-and-more.com) and restaurants (Tyson 2019). The goal in the first approach is quite simple however, complex systems can be designed on the collected data as well. Users create their profiles, so their transactions can be associated and tracked. Users collect points, achieve milestones or levels, and get privileges or discounts, while companies can execute data mining algorithms to analyze their behavior. The well-designed loyalty programs contain the most

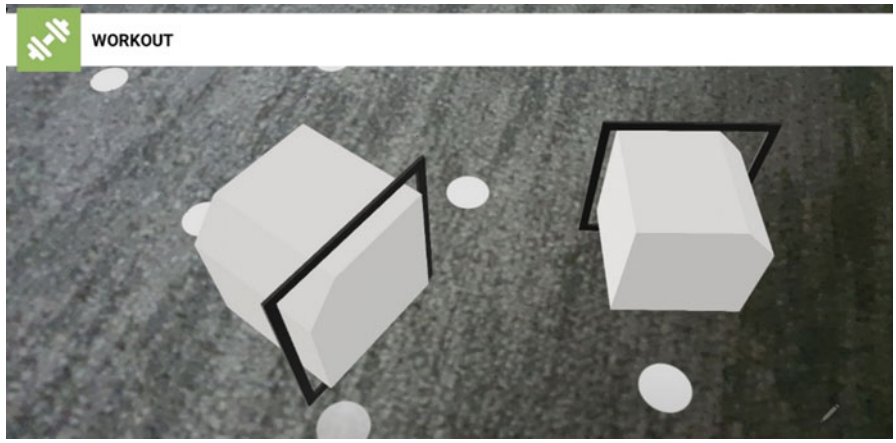
common elements of gamification. Fitness applications also use gamified elements to motivate the users in the hard process of diets. In the most popular applications, users can choose their goals, while the applications can automatically offer goals, rewards, reminders, and give feedback in the form of various statistics. However, in the last years, gamification elements are being applied to games that are distributed in various formats. Games with very simple logic and user experience implement the most common elements such as leaderboards, XPs, missions, time, and sociality to improve the user experience of the game. However, complex games and game stores also offer gamified elements to promote their products, engage and reward their users. On the other hand, well-known applications are starting to motivate their users to contribute by applying a few elements such as points, levels, and badges (see Fig. 2).

The first well-known AR application was released in 2016 in the form of a game which was based on a Japanese anime and its fictive characters (Rapp et al. 2018). The characters



Augmented and Gamified Lives, Fig. 2 Features of an application (Tóth et al. 2021) which offers Mental Cutting Test exercises to its users. Gamified elements can be implemented without changing the basic logic of the application

Augmented and Gamified Lives, Fig. 3 The visual cookbook uses an AR function to support its users who live with disabilities



Augmented and Gamified Lives, Fig. 4 The AR function of the previously mentioned learning application offers an opportunity to instantiate the model of the actual exercise and interact with it

were placed on selected geographical coordinates and users had to find and catch them with their mobile phones. Many other games are still be developed based on AR functions. People living with disabilities can be supported with AR applications designed to give some help for them in an activity that is trivial for others. Six European universities and a nongovernment organization run a project that focuses on how emerging technologies (including AR) can be used in developing such applications (Barbas et al. 2020). Figure 3 shows a visual cookbook application which is already published, where augmented image function is used to instantiate the ingredients of dishes (Pevec 2020).

Of course, AR is a perfect tool to be applied in education as well. Teaching and learning of courses where demonstrations are of high importance, can be supported by AR applications (Nørgård et al. 2018; Salinas et al. 2015; Grunewald Nichele and do Nascimento 2017). Thus, more students can access the extra information and online activities can also be supported (see Fig. 4). A well-known toy manufacturer company has also started to develop innovations with the use of augmented functions. Their applications are based on the augmented image function, offering the opportunity to instantiate the models of their current brochures (https://play.google.com/store/apps/details?id=com.lego.catalogue.global), while brand new product themes were also introduced massively built on augmented functions. Thus, children can interact with their sets gaining more experience. The largest tech-companies are also engaged in the mission to develop and distribute AR features to enhance the use of their products and provide tools for the developer community. The navigation of a well-known software (Ranieri 2020) now offers an AR function to provide useful information in an enhanced format, with the use of instant placement function. On the other hand, a new search function was also introduced with the use of which users can directly instantiate 3D models and interact with them (https://support.google.com/websearch/answer/9817187). Also, they provide a well-detailed and flexible used API for developers who want to develop their AR applications, based on the same core. Multiple platforms and devices are supported, that were produced in the last few years with the latest versions of operation systems. On the other hand, sample projects and the source codes of the development kits are published in public repositories (https://github.com/google-ar/arcore-android-sdk).

Cross-References

- ▶ Augmented Reality
- ▶ Challenge-Based Learning in a Serious Global Game
- ▶ Gamification and Serious Games

- History of Augmented Reality
- Mixed Reality

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Augmented Learning Experience for School Education

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Synonyms

Augmented reality; Gamification; K-12 education

Definition

Augmented reality is one of the technologies that works in real time to overlay virtual computer-generated graphics on to the real-world environment so as to provide the users with open-ended experience.

Gamification involves the use of several elements of game design in a context that does not actually belong to a game. This provides a playful experience to users and keeps them engaged and encouraged to attain the defined goals.

The K-12 education is a combination of primary and secondary education in schools which starts from Kindergarten, till 12th standard.

Introduction

The years are progressing with the development in technology. Augmented reality (AR), being one such technology, has been a key research area from quite a long time and has been applied in various domains. In the field of education and learning, several works have been done to improve the understanding and knowledge using AR. Gamification has been another means by which the students are made to be engaged with the experiential learning and stay motivated. With the advancements in the Internet usage and development of portable electronic devices, these two technologies are now reachable to everyone.

These means are being introduced in various sectors including education and learning to enhance the existing experiences. In the current education system, a lot of data is supposed to be memorized for writing the examination. This requires a need to reduce the cognitive load of the students with the developing technologies to make it easy for them to memorize and at the same time enjoy the learning experience.

In this entry, a case study on geography subject has been discussed to show a gamified way of learning maps using augmented reality for K-12 education system in schools to deliver better understanding, easy memorizing, and incremental learning.

K-12 Education System in Schools

With the advent of technology, K-12 education system in numerous schools is gaining importance and various methods of imparting knowledge have been adopted to make it more engaging for the students and enjoy the learning experience. In this form of education system in schools, a lot of attention is given to individual learning so that the students can on their own explore and develop their learning and understanding skills. Teachers are introducing various interactive activities as the mode of learning for the students to provide them an easier way of better understanding about what they are studying.

In many schools, blackboards are now getting replaced by projector screens to provide digital learning experience. Numerous schools are adopting such smart-class solutions where teachers project the digital content related to textbook on the screens for the students to better understand the concepts. These digital contents include 2D or 3D animations, audios, videos, etc. Students are also able to practice and learn at home on their own using various online modules. With the introduction of more evolving technologies and digital platforms in the K-12 education system in schools, it is believed that there will be growth and development in the learning capabilities of students.

Augmented Reality in School Education

The technology of augmented reality (AR) helps in interactively combining the virtual and real world in real time. AR systems are considered to work with the combination of various factors. It overlays the virtual information layer on top of the real surroundings instantly. The contents of the computer-generated virtual overlay have to be interactive and meaningful in the real environment (Azuma et al. 2001). In the course of many years, the importance and application of AR has been realized in several domains.

AR helps to visualize the virtual objects as real. One can see the live 3D representation of the computer-generated virtual imagery data. It can thus help students to interact with the 3D spatial structures and enhance the learning skills. In the field of school education, the applications of AR was realized in some of the subject areas that included astronomy, chemistry, biology, mathematics and geometry education, and physics (Lee 2012). Through the evolution of gadgets like personal computers, smartphones, tablets, and other electronic innovations, AR has become more powerful in becoming a prominent technology.

The AR technology in school education can be observed through mediums like AR books, objects modeling, AR games, discovery-based training, and skills training (Yuen et al. 2011). AR can potentially increase the collaboration and understanding between teachers and students in classroom. While teaching in classes, many a times the teachers and students are not on the same mental platform. Teachers try to make the students visualize some concepts in 3D but are unaware if the students are able to do it or not. With the application of AR, now the 3D representation of the concepts is shown to the students in class which highly aids their understanding. Classroom learning using AR gives a very engaging experience where students can look at things from every angle and this turns to be very useful in explaining many things from textbook like the solar system, atomic structures in chemistry, etc. AR books are also an important innovation which bridges the

gap between the digital and physical world. Because books are printed media, they have some limitations like poor printing quality, dullness, etc. But the conversion of 2D contents of the textbook into 3D objects in real environment helps to enhance the learning experience. Such tools have also been developed which can convert 2D sketches into 3D objects, using which students can develop 3D models in space. A lot of applications have been developed around games in AR as it is believed that games can play a key role in keeping students motivated and can also help them in grasping the concepts easily. There are some AR applications which during the field trips to museums, historical spots, caves, etc. display the overlaid information on the real environment, making it an interactive learning experience. Thus, the means of providing the AR experience may vary with the mode of teaching.

Memorization Using Augmented Reality

In the school education system, there are multiple subjects in each standard. Further, each subject has multiple chapters which the students have to understand, learn and recall at the time of examination. Thus, the students find it a challenging task as there is a lot of data that they have to memorize.

Several researches have been done to find the relationship between AR and memorization for providing a better scope in school education. Among the recent works, the use of an AR application has been observed to display visual directives at the location of some drawers for easy memorization of the visually displayed objects (Fujimoto et al. 2012). In some cases, marker-based AR has been used to make users learn foreign language by displaying 3D objects and their corresponding spelling and pronunciation (Beder 2012). Among the various techniques to memorize, memory palace memorization method where a user makes use of the familiar spaces to construct their respective memory palace to memorize has been applied and observed using AR (Rosello et al. 2016).

The traditional method of classroom teaching in schools can be improved by providing the students with interactive visualization of 3D objects to give them the real-life interactive experience to understand better and enable easy retention of the shown content.

Gamification in Education

Gamification helps a student to stay engaged and motivated with the learning methods. It is now emerging as a useful tool in various domains including school education. Viriyapong et al. developed a game that helps in escalating the learning experience of mathematics for high school students using game methods. With the focus on plotting linear and polynomial functions on graph using coefficients, the game motivates the user by providing points for each correct answer based on the time taken to answer. The difficulty level increases at each level of the game (Viriyapong et al. 2014). Another game is being designed that uses spaced repetition with a gamified experience to enhance STEM (science, technology, engineering, and mathematics) education for students of K-12 education system (Yeh et al. 2016). Many such gamified experiences have been provided across various subjects for the students to stay motivated toward learning new concepts.

For the implementation of gaming in AR, several elements can be used such as points, levels, badges, experience points, leaderboards, challenges (Nah et al. 2014). The introduction of these elements brings up engagement, participation, motivation, enjoyment, performance, recognition, status, sense of accomplishment, and sense of achievement in any game. But it becomes difficult to make the whole game, especially an educational game interesting and motivating by using only one of these elements. Best results are obtained when these elements are used in combinations where they are interlinked with each other. These elements are to be incorporated in the game in such a way that it connects the student with the gameplay and their fellow players.

Combining Augmented Reality and Gamification in Education

Various attempts have been made for combining AR and gamification in the field of school education. AR system can be either marker-based or marker-less (Johnson et al. 2010). In marker-based AR system, the camera of the device first identifies the marker related to any image or associated data, then matches with the related content in the database, and finally superimposes the related 3D visualization and/or audio onto the real world. Marker-less AR on the other hand does not require any former information about the real world environment. It instead involves the use of GPS and compass of the AR device connected through Internet and applies image recognition methods to track certain defined features in the live environment and overlay the virtual content onto it.

Virtual laboratories in the real world are being introduced using "markers" to provide interactive hands-on learning and experimental experience for learning and education (Eleftheria et al. 2013). In this, a science AR book was created along with gamification. The knowledge and learning was tested through several challenges as part of game.

In another AR game, the use of GPS, compass, and Internet in a hand-held device, enables students to discover why the aliens entered the earth (Dunleavy et al. 2009). In the AR environment created, the students interact with the computer-generated characters, digital objects and solve related puzzles based on math, science, and language arts.

Thus, the feature of memorization using augmented reality and motivation using gamification can be combined to further enhance the learning capabilities of students and make it an enjoyable experience for them.

Case Study: Applying AR and Gamification in Geography

In the existing K-12 education system in schools, there is a lot of data that needs to be memorized by students to perform well in their examinations. The system focuses on dividing the whole content in appropriate modules with required amount of data and takes few examinations based on that. However, this kind of school education lacks enough motivation for the students to stay engaged with the subjects. In many subjects that are related to real life, students find it difficult to correlate because the pictorial contents they have in their books are in two dimensions whereas in real environment they are in three dimensions. Among the various subjects that the students have to learn, geography is one such course that involves a lot of information to understand as well as memorize for writing examinations. In this subject, it becomes difficult to visualize things in three dimensions, and it turns out to be even more difficult for the teachers to teach and make the students understand. In every standard, starting from class 5, the students are made familiar with different type of maps, the way to read them and the way to find latitude and longitude of a location in the map using atlas or vice-versa. Since, there is a lot of textbook data and numerous locations that the students have to keep in mind, this results in students losing the interest in that subject and studying it just for the sake of examinations. Thus, the design of an AR-based game for learning the maps easily and with interest has been further discussed.

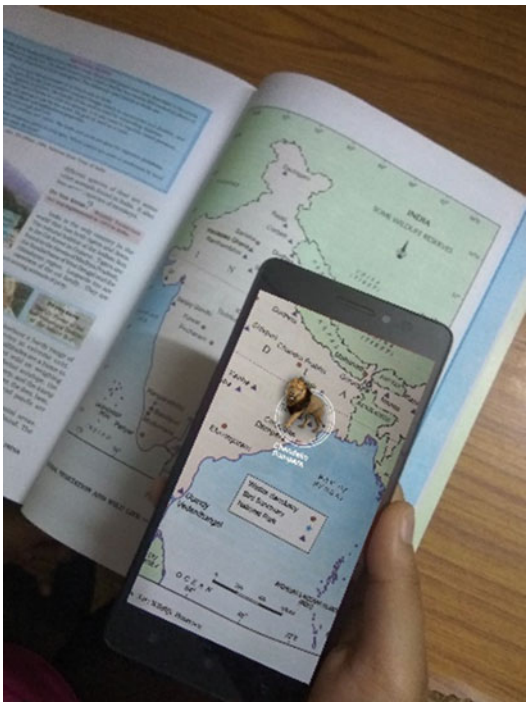
The two methods, marker-based and marker-less AR are being extensively used and explored in various works on school education. However, in this case study the use of marker-based approach has been emphasized upon for the existing geography textbooks.

In the design, augmented reality has been used to make the contents more interactive. Additional printed AR markers are provided corresponding to each map in the textbook. On scanning the markers with the AR device, users can see the maps in 3D. In the maps which show terrains, wind movements, etc., users are able to see those visual contents in three dimension. This application is based on two modules. First is to help the users memorize the locations as well as understand the related concepts and the second one is

to help them practice to mark the locations on the map.

In order to memorize the locations on the map, a 3D visualization of the map is augmented. If it is the map of wildlife reserves, for example, when the AR device is brought on the 2D map, the 3D visualization of the corresponding wildlife reserve on the map gets projected. This is followed by popping of names and related brief information in a sequential manner. The users have the option to revise the locations as many times as needed. Once the names of the wildlife reserves with their locations are memorized, one can proceed to play and score (Figs. 1, 2, and 3).

In the game, within 20 s, one has to mark a list of 12 locations. The user has the option to choose the type of map to practice with the help of the marker. The maximum number of locations marked within the time limit provides better scores. The property of spaced repetition has been used in this game for easy retention of the content. The short time limit challenge in the game helps in getting motivated to challenge their own retention capability. The user can get to see their performance on the progress meter for every time they play which ultimately help to develop confidence (Fig. 3).



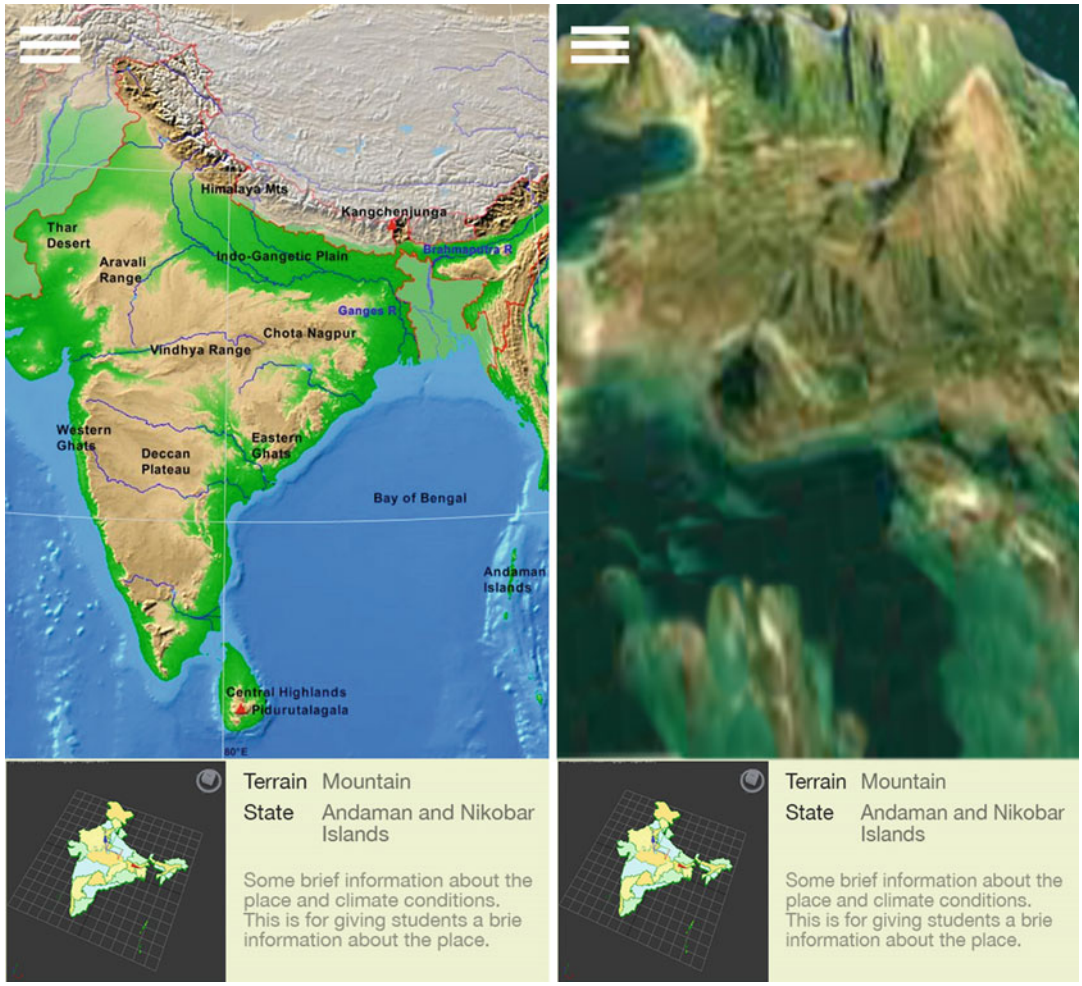
Augmented Learning Experience for School Education, Fig. 1 Demonstration of prototype

The progress meter of every player is reflected on their profile. When they feel they are confident in a topic they can raise challenges with their friends. The application persuades the user to take up challenges with the friends of their class or locality as on winning a challenge the user earns twice the number of points as compared to normal practice mode. This encourages the user to take more number of challenges.

The game consists of scores, levels, and badges for the users to stay motivated in learning the maps quickly on their own with enjoyment. For every 1000 points a level is attained and the user gets a badge for that which shows their proficiency. The user also gets badges for certain defined tasks. For example, on scoring 100 points on 3 different maps the user gets a new badge. Similarly, the user can get 25 different badges on performing such defined tasks.

Limitations of Augmented Reality

AR has significantly helped to improve the learning experience in classrooms but some issues of using AR have also been observed, most of which are the hardware and software problems (Dunleavy et al. 2009). Cases have been seen where students find it challenging to learn the new technology and respond to the corresponding activities in timely manner, thus developing some cognitive stress. In the classroom experience, at times it becomes difficult for teachers to manage the student groups involved in doing AR activities. The students also tend to lose track of their surroundings while performing the AR-based activities as they get totally involved in that. On the development end, at times it becomes difficult to create and deploy highly rendered 3D objects. This thus leads to making low-poly objects instead, which might provide less clarity in visualization. However, these challenges may be

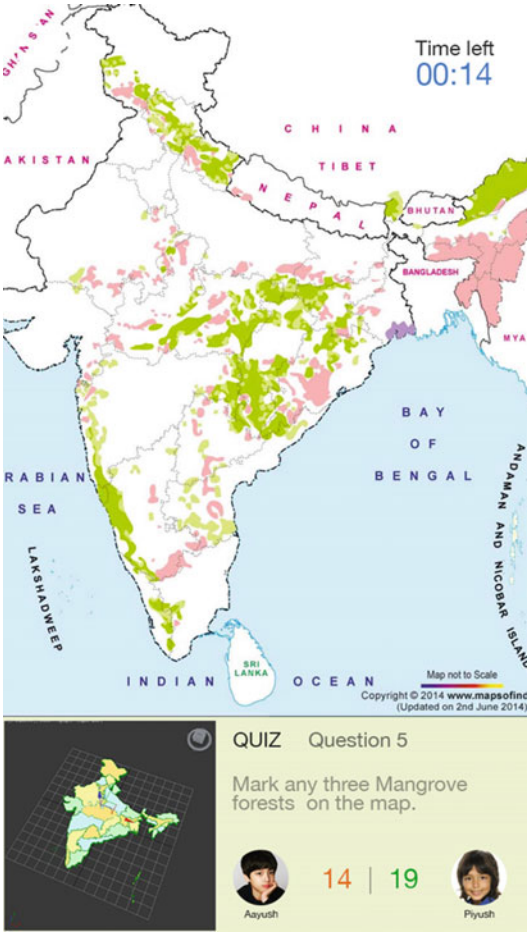


Augmented Learning Experience for School Education, Fig. 2 3D visualization of topographical map in AR

worked upon with the passage of time to provide a better AR experience.

Conclusion

This entry discussed the scope of augmented reality in school education to enhance the learning experience of students. Several researches are being done to improvise the traditional form of textbook-based teaching so as to reduce rote learning effort made by the students. Augmented reality instead provides an engaging interactive experience to share knowledge through visualization in the real world. There are various means like AR books, AR games, object modeling, and many more, by which this augmented reality–based teaching and learning is done in school education. To keep the students motivated with their learning skills, AR-based games are also introduced. These games have combination of game elements like points, levels, badges, leaderboard, etc. to encourage their participation in the game-based learning (Deterding et al. 2011). AR and gamification together makes it interactive and motivating for the students to learn easily and can help to reduce the memorizing efforts being put by the students. In the entry, one such case study on



Augmented Learning Experience for School Education, Fig. 3 Opponents competing in a stipulated time limit

learning the maps in geography using AR-based quiz game is discussed. However, there are certain limitations while using AR in school education. These include software and hardware limitations, deployment issues with highly rendered 3D objects, skills of the teachers and students to adapt to the new technology, managing the student groups, intensive involvement and avoiding the current surrounding happenings, etc. These challenges may be overcome with the evolution of the technology reachability over time. Thus, the learning can be made to be a more enjoyable experience with augmented reality getting introduced in the school education.

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Augmented Reality

▶ 3D Puzzle Games in Extended Reality Environments
▶ 3D Selection Techniques for Distant Object Interaction in Augmented Reality
▶ Artificial Reality Continuum
▶ Augmented and Gamified Lives
▶ Augmented Learning Experience for School Education
▶ Augmented Reality Ludo Board Game with Q-Learning on Handheld
▶ Conceptual Model of Mobile Augmented Reality for Cultural Heritage
▶ History of Augmented Reality
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▶ Shadow Shooter: All-Around Game with e-Yumi 3D
▶ Tracking Techniques in Augmented Reality for Handheld Interfaces
▶ Virtual Reality and Robotics

Augmented Reality Displays

▶ Enhanced Visualization by Augmented Reality

Augmented Reality Entertainment: Taking Gaming Out of the Box

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Synonyms

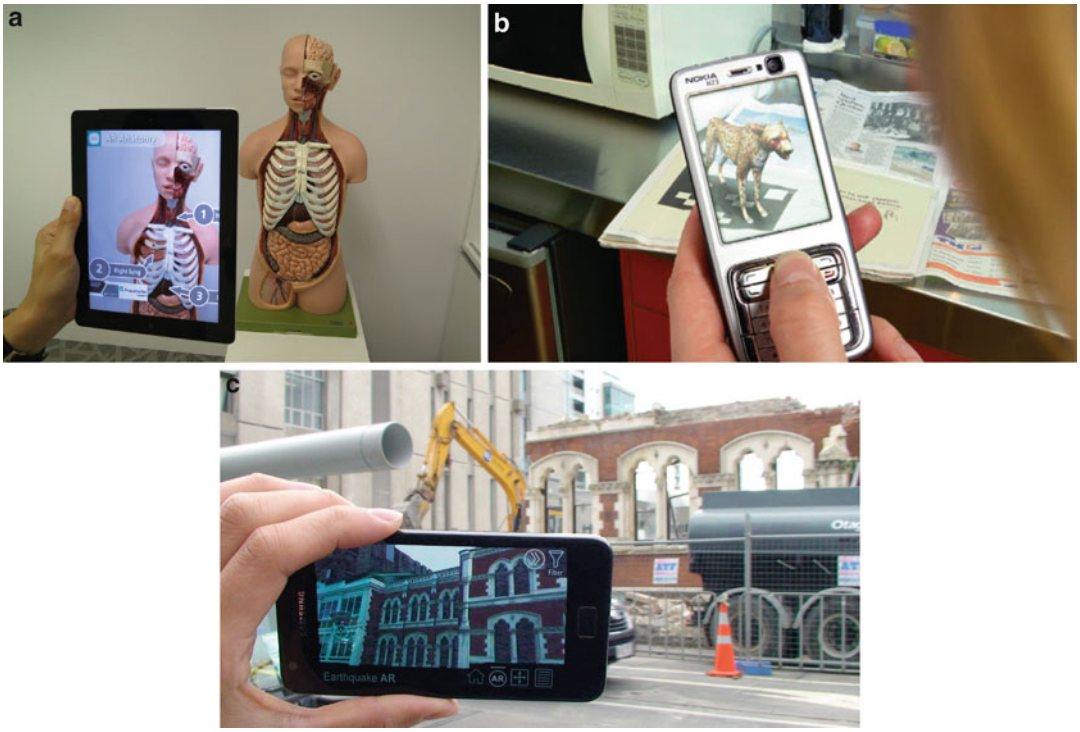
Augmented reality gaming; Spatial augmented reality gaming; Virtual reality entertainment; Virtual reality gaming

Definition

Augmented reality (AR) is technology that seamlessly adds virtual imagery over a view of the real world, so that it can be seen and interacted with in real time. Azuma says that an AR system is one that has three key defining characteristics (Sutherland 1968): (1) It combines real and virtual content, (2) It is interactive in real time, and (3) It is registered in 3D.

Introduction

AR can be used in many possible application domains, such as in medicine to show virtual anatomical structures in a real patient's body



Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 1 Examples of AR experiences (**a**) medical, (**b**) marketing, and (**c**) architectural

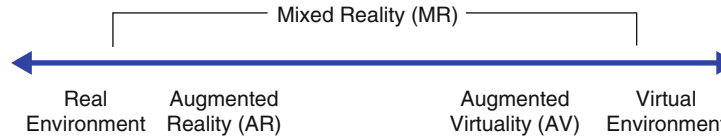
(Fig. 1a), marketing where computer graphics appear to pop out of a magazine (Fig. 1b), and architecture where unbuilt virtual buildings can appear in the real world (Fig. 1c).

In this chapter, an overview of using AR for gaming and entertainment is provided, one of the most popular application areas. There are many possible AR entertainment applications. For example, the Pokémon Go mobile phone game has an AR element that allows people to see virtual Pokémon to appear in the live camera view, seemingly inhabiting the real world. In this case, Pokémon Go satisfies Azuma's three AR criteria: the virtual Pokémon appears in the real world, the user can interact with them, and they appear fixed in space.

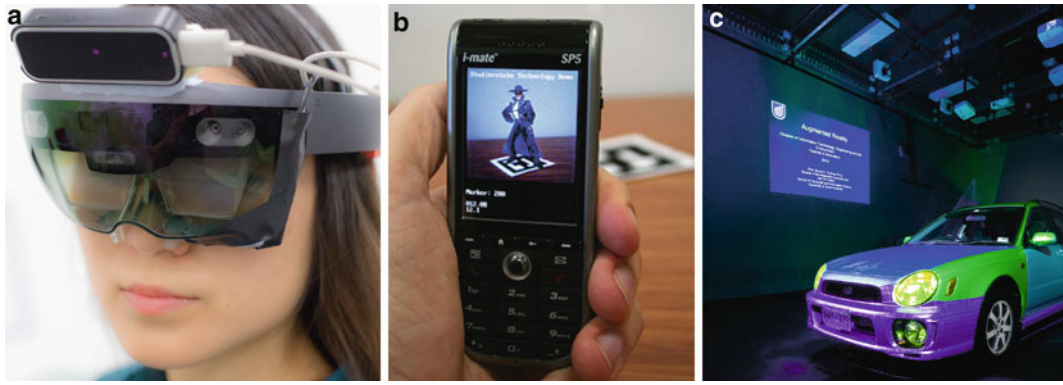
AR is complimentary to virtual reality (VR), technology that tries to fully immerse a person in a computer-generated environment. While AR uses virtual information to enhance a user's interaction in the real world, VR separates people from the real world entirely. AR and VR can both be placed on Milgram's virtuality continuum (Milgram and Kishino 1994) that arranges computer interfaces according to how much of the user experience is replaced by computer graphics (Fig. 2). At the left end of this continuum is the real world with no virtual information, while VR is at the right end, where the user's entire experience is computer generated. Mixed reality is everything in between, including the overlay of virtual content in the real world (AR) and adding elements of the real world into VR (virtual reality).

Augmented Reality Technology

Azuma's definition of AR provides guidance as to the technology required for AR entertainment systems. To combine real and virtual content, there needs to be some display technology where both can be seen at the same time. To allow the user to interact with the virtual content, there needs to input technology. Finally, to create the



Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 2 Milgram's virtuality continuum and mixed reality technologies



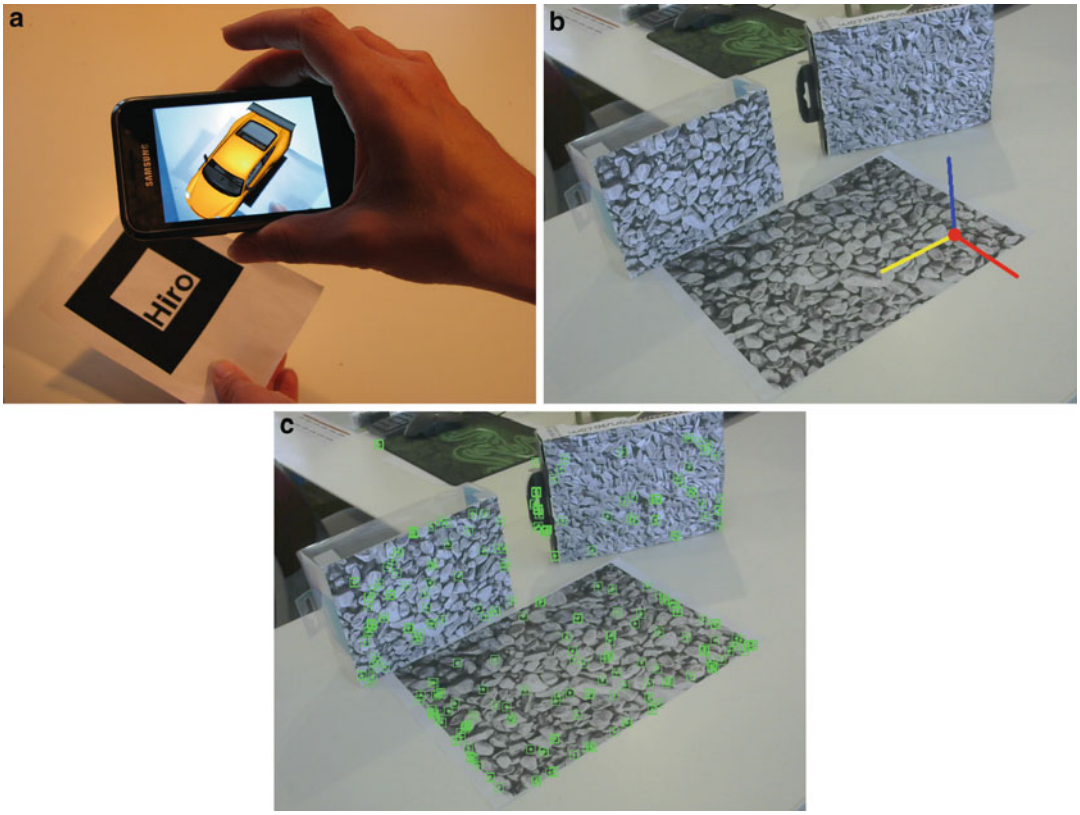
Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 3 (**a**) Head-mounted AR, (**b**) Handheld AR, (**c**) Spatial AR

illusion that the virtual content is fixed in space tracking technology needs to be used to track the user's viewpoint.

There are a wide variety of AR displays, which can be categorized into three types depending where the display is placed: head-attached, hand-held, and spatial (Davis et al. 2007) (Fig. 3). Head-attached displays include head-mounted displays (HMD), head-mounted projectors, and retinal projection systems which shine images directly into the eyes. AR HMDs can be optical see-through (OST) which use transparent optics to enable the user to see virtual images directly overlaid on the real world, or video see-through (VST) which displays computer graphics overlaid on a video of the real world. Hand-held AR displays are the most common and include devices such as mobile phones, tablets, and small projectors. Finally, spatial displays are those that include using a fixed projector to shine virtual content onto a real object, such as a car, and are often used as public displays for multiple people.

In terms of interactivity, there are a wide variety of different input devices that can be used, often depending on the type of AR display. For example, for hand-held AR the display screen is usually touch-enabled and so many hand-held AR systems use touch input. Some HMD-based AR systems have additional sensors that track the users' hands and so enable gesture interaction. In this case, it can be very natural for users to reach out and grab the virtual content that appears in space directly in front of them. Finally, for spatial AR the experience is often at a larger scale and so cameras can track a user's full body motion to enable them to interact with the AR content.

The final requirement for an AR system is to have some form of user viewpoint tracking so that the AR content can appear fixed in space while the user moves around. There are many different tracking approaches that can be used; however, for indoor-based systems, computer vision methods are the most popular. Marker-based computer vision tracking enables a user to point a hand-held or head-worn camera at a known printed image, have the camera pose calculated relative to the image, and then draw graphics overlaid on the marker (Fig. 4a). More recently, software has been developed that supports simultaneous localization and mapping (SLAM) and can calculate the camera's position without knowing anything about the users' environment (Fig. 4b). Outdoors, it is common to use GPS-



Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 4 (**a**) Marker tracking, (**b**) SLAM Tracking Points (Courtesy of Huidong Bai), (**c**) SLAM Axis Overlay (Courtesy of Huidong Bai)

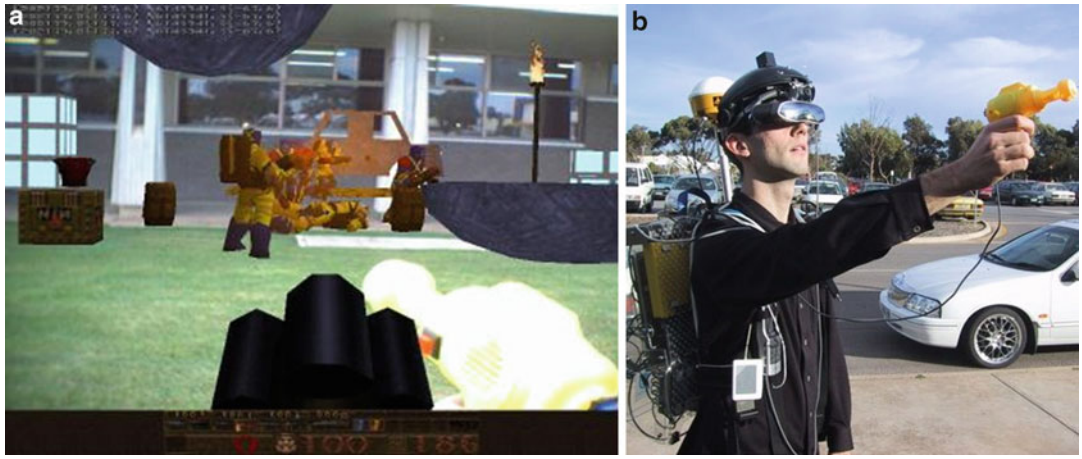
based systems combined with computer vision or inertial compass input to find the user's location. Most mobile phones have cameras, GPS, and inertial sensors in them and so have all the technology needed for AR tracking.

History of Augmented Reality Gaming

The history of AR gaming applications began nearly fifty years ago. In 1968, Ivan Sutherland created the first complete AR system with a very bulky see-through head-mounted display (HMD) connected to a mechanical head tracker, showing very simple graphics (Sutherland 1968). Following on from this the US military experimented with HMDs and heads up displays (HUDs) that were designed to overlay vehicle instrument information over the real world, for example providing a pilot with an AR view of instruments while flying.

In the late 1980s, several universities began conducting research in the AR space, developing various fundamental technologies. For example, at the University of North Carolina researchers created novel AR displays and tracking technology. The University of Toronto had scientists exploring input devices and the human factors of AR, while people at the University of Washington and Columbia University explored collaborative and mobile AR systems, among other topics.

By the mid-1990s, enough basic research had been completed that people could begin to explore the application space. The first complete mobile AR systems were developed using backpack computers, and people began to explore how AR could be applied in medicine, education, engineering, and other areas. For example, engineers



Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 5 (**a**) ARQuake. Player view, (**b**) ARQuake. Backpack system

at Boeing were using AR to help with creating the wire bundles for aircraft. Boeing engineer Tom Caudell published the first research paper with the term "augmented reality" in it (Caudell and Mizell 1992), and this led to many other companies developing industrial applications.

By the early 2000s, the underlying technology was reaching maturity, and so the first widespread entertainment applications of AR began to appear. In 2002, ARQuake (Thomas et al. 2002) was an early port of a popular commercial game to a backpack AR system. The Quake game was modified to use a real university campus as the setting for an invasion of monster's players run around the real campus seeing virtual monsters moving around in the campus setting (Fig. 5). This became a forerunner of many mobile AR games that were released a decade later on mobile phones.

Around the same time, there were several examples of indoor AR gaming experiences developed. This includes the indoor mobile AR game, MIND-WARPING (Starner et al. 2000). This employed an HMD and allowed users to physically walk/run throughout a floor of a building fighting with virtual monsters that were controlled by a second remote player on an interactive table top display. The mobile nature of the equipment allowed for AR information to be attached to physical locations in the space, to tracked physical objects, and to the game players. This created a new type of location-based gaming experiences.

The employment of a table top as an AR gaming surface provides for several interesting user interface opportunities for HMD, hand-held or table top-projected AR entertainment applications. The games may range from extensions to traditional non-computer-based games, such as AR Chinese checkers (Cooper et al. 2004) to new robotic interaction games such as Augmented coliseum (Kojima et al. 2006). There are many advantages to playing games on a computer rather than on a physical board, such as the ability to introduce animation and other multimedia presentations. The animation can do more than add excitement to the gameplay, it can also help the players learn the game and understand invalid moves.

In 2006, Fox Sports began to implement AR into their sports broadcasts. Initially, limited to NFL football, it later moved to other sporting codes. AR was used to show the player stats and scores as a virtual billboard that occupied an unused section of the field. More recently, BT Sports in Europe has introduced AR technology for describing soccer plays (Fig. 6), and AR enhancements were shown in the most recent Olympics.

In 2007, Sony released the Eye of Judgement game. This used a camera with the PlayStation

Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 6 AR soccer strategy (BT Sport)

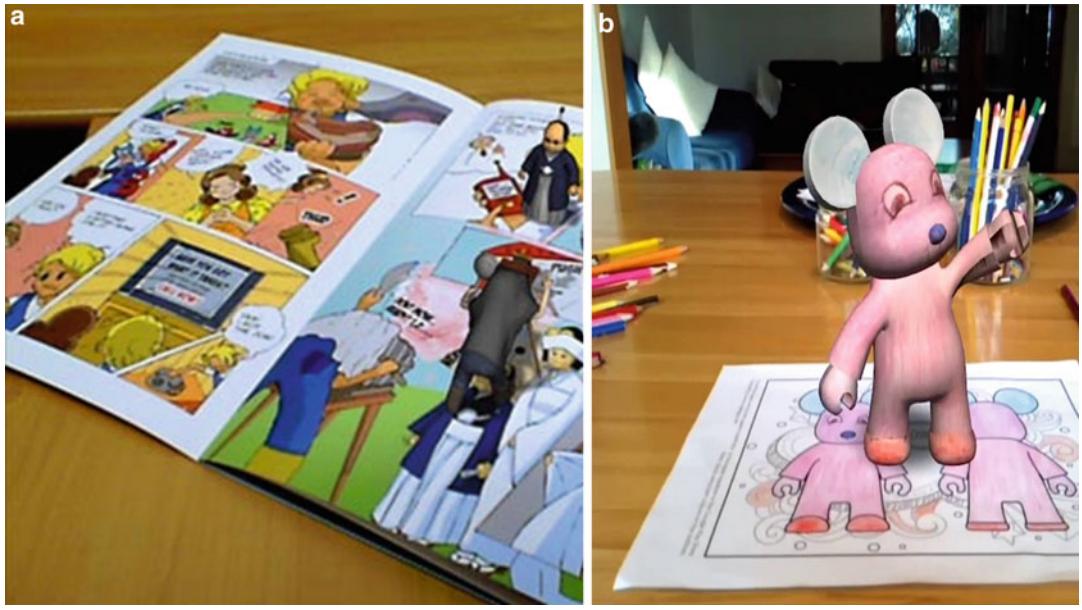
console to show virtual monsters on real cards. It was a face to face multiplayer game where players looked at a TV screen to see the AR view. The game used the camera to show a live view of the cards overlaid with virtual game characters. As players put the cards next to each other, the animated characters would battle each other. It sold over 300,000 copies, making it the most successful AR entertainment experience at the time.

Around the same time processing and graphics power on mobile phones had grown to the point where they could run mobile AR applications. The first AR computer vision application for a mobile phone appeared in 2004 (Mohring et al. 2004), followed soon after by AR Tennis, the first collaborative AR game on a mobile phone (Henrysson et al. 2005). In AR, Tennis players sat across from each other playing an AR tennis game using their phones as real rackets, viewing virtual content attached to a real marker between them. By 2007, phones had integrated GPS and compass sensors in them enabling the first mobile phone outdoor AR experiences, such as viewing virtual buildings in the real world. This opened AR to the masses and allowed developers to build a whole new class of entertainment applications.

Current Augmented Reality Entertainment Applications

Following from the early beginnings reviewed in the previous section, there are a wide range of current AR entertainment applications that show how AR can be used in many different entertainment domains. Initially, AR mobile apps were simple and used for information browsing applications such as a bank app that places virtual tags in the real world showing were ATM machines are. Recently, these AR apps have branched into location-based gaming with the most well-known being Pokémon Go (2017) (and its predecessor Ingress). These games allow players to travel to a location and do battle with virtual enemies which are overlayed on the real world. Being the fastest mobile app ever to achieve more than $1 Billion USD in revenue, Pokémon Go shows the huge potential that combining location-based gaming, AR and a well-known brand can have.

Another popular category for mobile AR is interactive books and coloring experiences. Beginning with the MagicBook (Billinghurst et al. 2001), there are many AR book experiences. Typically, these allow users to view a normal book through their mobile phone and see the pages come to life with interactive AR content (Fig. 7). These are particularly popular for children's stories or educational books. A variation of this is the AR coloring application which allows children to color pages and then see AR content appear out of the page with their colors on the content. This was popularized by the company Quiver (Website 2017), but has since been developed by dozens of other companies around the world. Children really enjoy being able to see



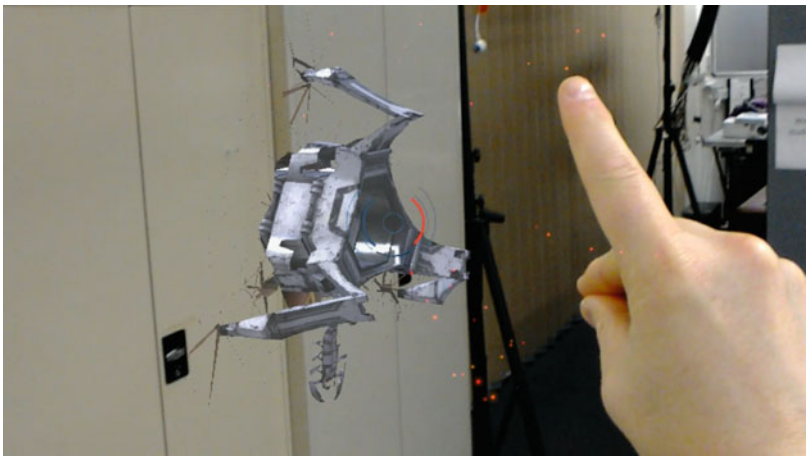
Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 7 (**a**) AR book, (**b**) Quiver AR coloring book

Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 8 Microsoft RoomAlive (Courtesy Microsoft Research)

virtual characters that they have colored come to life.

Spatial AR technology has been used to create room scale AR entertainment applications. For example, Microsoft's Room Alive spatial AR system turns living rooms into interactive AR play spaces (Jones et al. 2014). Depth-based cameras are employed to map the real environment and to capture gestures and movements of people in the space. In this way, graphics can be seamlessly projected on the walls and the user can move freely around the space and interact with the virtual content (Fig. 8). For example, a hand-held gun prop can be used to shoot the virtual creatures in the living room.

There are few widely available AR HMDs, but the Microsoft HoloLens (Website 2017) shows the type of AR HMD-based entertainment



Augmented Reality Entertainment: Taking Gaming Out of the Box, Fig. 9 Augmented reality gaming. Microsoft HoloLens RoboRaid

experiences that are currently possible. The HoloLens contains depth sensors that can map the user's surroundings, allowing an application to make use of the surrounding environment and annotate 3D objects over that environment. A good example of this is RoboRaid (Fig. 9:) where the user's room is attacked by aliens that break through the real walls and try to defeat the user. This is achieved by the HoloLens creating a 3D map of the room and interpreting where the physical walls are in the room them allowing the game to apply game oriented textures to the walls.

Conclusion

As can be seen from the previous sections, AR has a long history and entertainment is one of the widespread uses today. AR is pervading industry with new start-ups appearing almost weekly, while older established corporations, such as Apple, have been buying up these start-ups almost as fast as they appear. It's clear that they see a future in the technology.

One of the reasons for this growing popularity of AR is that it offers a fundamentally different entertainment experience. Non-AR experiences typically focus the user on a screen (mobile games) or completely immerses them into a digital space (VR). On the other hand, AR expands the users' interaction with the real world, whether encouraging people to walk outside to find Pokémon's, or motivating children to read more by turning their books into an AR play space.

Another area of endeavor is allowing users to grasp and feel the texture of virtual objects in AR. Devices such as Massie's Phantom (Massie and Salisbury 1994) provide a mechanical arm held by a user's fingers allowing computer-controlled haptic feedback to be programmed. Simon et al. (2014) have been investigating the use of a technology called layer jamming to provide haptic sensations with the low-profile actuator that is encapsulated in a mitten. This technology has both benefits in that it is low profile but disadvantages as it requires a vacuum source to activate the actuators providing the stimulus.

Spatial augmented reality (SAR) (Fig. 3c) has a lot of potential for gaming and entertainment as it is not a solitary experience. Because the projections are independent of the user, many users can participate in a shared experience; most other AR approaches do not directly support shared gameplay due to the nature of the projection, e.g., helmet or phone. SAR games could include shared gaming environment (AKA Star Treks' Holodeck) where people share the experience. However, due to the added a complexity, cost and calibration challenges it has not been adopted at the same rate as other forms of augmented reality. Cooperative and competitive games will become very playable once the problems of cost and calibration are solved satisfactorily.

Overall, AR provides unique entertainment options not available with other types of

digital media. However, in many ways developers are still just beginning to explore the full potential of AR for entertainment. With new devices and research outputs becoming available, future AR systems will be a significant advance over those available now. There is a bright future ahead for AR entertainment experiences.

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Augmented Reality for Human-Robot Interaction in Industry

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Synonyms

Collaborative robot augmented reality; HRI AR; Industrial robot augmented reality

Definitions

Augmented reality for human-robot interaction in industry is the usage of augmented reality technologies for displaying computer-generated digital contents, correctly aligned to real objects, in order to enhance and enrich the communication interface of users, which operates robots in an industrial environment.

Introduction

The industry domain has taken advantage of augmented reality (AR) since its origin (Sutherland 1968): technicians are often

involved in complex assembly, repair, or maintenance procedures, and they need to refer to instruction manuals to complete their tasks (Caudell and Mizell 1992). However, these activities often require a high cognitive load due to a continuous switch of the attention between the physical device and the paper manual (Henderson and Feiner 2007). AR can efficiently overcome this issue providing the same content in a digital form and properly displayed on the physical object involved in the task.

In this entry, AR technologies adopted to visualize digital contents in industry, the different kinds of robots involved in, and the most common tasks which benefit of AR contents are discussed.

Technologies

Among human sensory inputs, sight, hearing, and touch are currently the senses enhanced by an AR system through digital contents. However, since industrial environments may provide different kinds of limitations depending on the task, such as anti-noise headphones or gloves, the AR content is usually provided visually. Different devices can be adopted to display the AR content depending on the task and the environment. Overall, an AR system is characterized by three blocks: a tracking system, a content generator, and a combiner.

Tracking System

The tracking system has the task to establish an absolute reference system, based on some features related to the environment: this reference system is fundamental to properly display the augmented reality content with respect to the user's view and the real-world objects. The tracking system is called object dependent if the reference system depends on the position of a real object: this kind of systems adopts computer graphics algorithms to identify the object from frames of the environment provided by a digital camera. Other, less common solutions consist of inertial, mechanical, and magnetic tracking systems or involve the usage of absolute references such as GPS coordinates (Foxlin 2002).

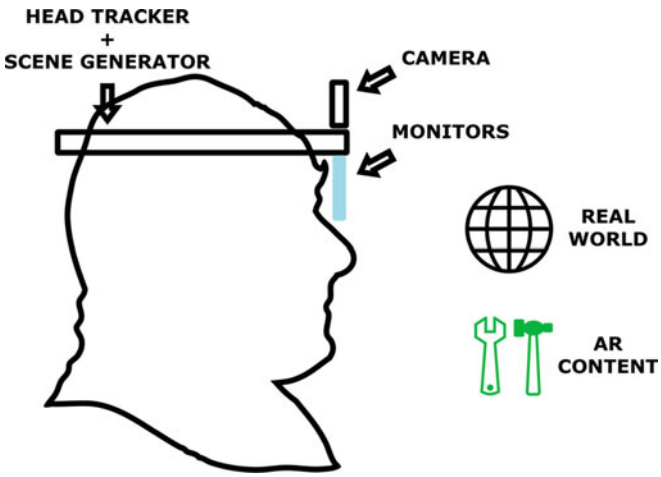
Content Generator

The content generator has the task to compute the graphical content to be displayed depending on the coordinates provided by the tracking system and the frames provided by the digital camera.

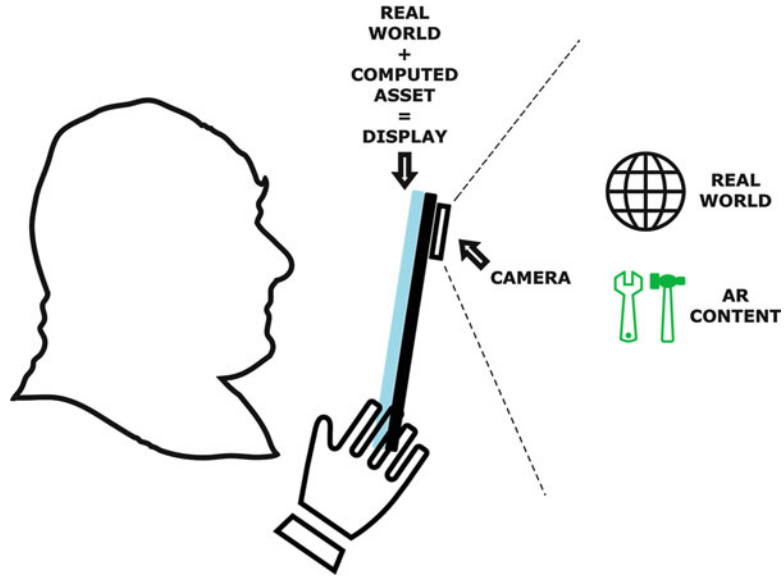
Combiner

The combiner has the task to overlap the assets to the user view. It acts in different ways according to the used AR paradigm.

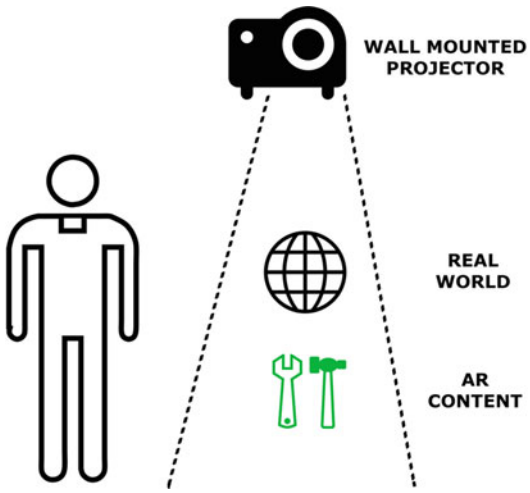
Optical see-through devices blend physical and virtual objects holographically using transparent mirrors and lenses (Fig. 1). These devices are wearable and most of the time also mobile.



Augmented Reality for Human-Robot Interaction in Industry, Fig. 1 Optical see-through AR system



Augmented Reality for Human-Robot Interaction in Industry, Fig. 2 Handheld AR system



Augmented Reality for Human-Robot Interaction in Industry, Fig. 3 Projective AR system

Moreover, since it is possible to wear them like glasses, the user's hands are free, which is usually mandatory in industrial tasks. One disadvantage of this kind of devices is the limited field of view that may cause clipping of virtual images at the edges of the mirrors or lenses. Moreover, it is difficult to occlude a real object because their light is always combined with the virtual image due to the lenses properties. Finally, other devices (e.g., physical trackpad, joypad, or keyboard) are required to be added to the system to provide a proper interaction interface.

Handheld technologies include all the devices that allow to display both the physical world, recorded through a camera, and the AR content on a display (Fig. 2). These devices are usually mobile, e.g., smartphones and tablets, since the user needs to freely move them in order to frame the point of interest in the environment and experience the AR content. The most common disadvantages of handheld devices are two: firstly, the need to use one or both hands to handle the devices, thus making them unavailable to perform tasks; secondly, the user may experience disorientation for parallax effect due to the camera position with respect to the viewer's true eye location.

Projective devices allow to directly display AR contents over physical objects (Fig. 3). They do not require special eyewear and accommodate the user's eyes during focusing. Moreover, they can cover large surfaces for a wide field of view. In the industrial domain, these devices are usually adopted to display AR content on a big industrial robot, such as robotic arms. Commonly, projection surfaces may vary from flat, plain colored walls to complex scale models. The main limitation of this technology is that the AR content is perceived as bidimensional instead of three-

dimensional. Other common disadvantages comprehend occlusion and the need for other input devices for interaction. Moreover, projectors need to be calibrated each time the environment or the distance to the projection surface changes.

Robots

AR technologies are usually applied to human-robot interaction (HRI) with two categories of industrial robots: robotic arm manipulators and automated guided vehicles (AGVs).

A robotic arm manipulator is defined as an n-degree-of-freedom (nDoF) arm robot. It is composed of links connected by joints that are controlled by using either DC or brushless electric motors. Their positions are sampled by means of encoders, and the joints' velocities are measured with tachometers. Joints are divided into two different categories: revolute and prismatic. Revolute joints allow rotations along one local axis (usually the z-axis), whereas prismatic joints allow translations along one local axis (usually the z-axis). Robotic arms are also equipped by different custom tools depending on the task to accomplish: these tools are positioned at the end of the kinematic chain and are called end-effectors.

AGVs are vehicles that can move along predefined path and predetermined directions automatically and autonomously, without human interference. They are usually equipped by sensors that allow them to identify and eventually avoid obstacles along their path. Their primary task is to transport equipment around a manufacturing facility. AGVs are equipped with automatic guiding, either electromagnetic or optical, they can follow a predefined path through visual analysis of a familiar environment, or they can use vision system to understand their location in an unknown environment.

Tasks

Depending on the type of robot considered and its task, various types of AR systems are adopted, and different AR contents are provided to the user. When used with robotic arm manipulators, technicians can benefit from AR systems to visualize one or more of the following features: end-effector path, end-effector direction, object (s) manipulated or involved in the task, workspace involved in the robot task, forces applied by the end-effector, and faults that occur on the industrial manipulator. When used with AGVs, the features visualized through AR usually consist of the path and workspace of the robot. In the following, each feature will be introduced and explained.

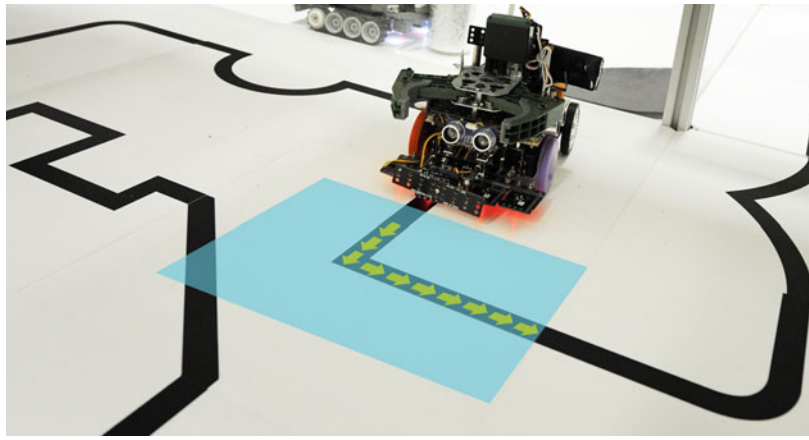
Path

Depending on the types of paths and trajectories, different AR systems can be adopted. Trajectories can be divided in 2D paths and 3D paths. The first ones are usually visualized on 2D areas using projectors mounted directly on the industrial manipulator or on appropriate supports placed nearby the robotic arm. They normally consist of one or more connected lines of the same color. The 3D paths are visualized in the real environment by means of wearable or handheld devices. It is possible to interact with both types of path using some specific tracked devices to modify them: this allows users to change the trajectories of the industrial manipulator through the interaction with the augmented reality paths.

When displaying the path of an AGV, since these robots freely move around all the environment, the AR projection system is commonly placed directly on the mobile robots. Thus, workers can work without wearing ad hoc AR devices. AGVs are equipped with projectors that allow to visualize the AGV's intentions directly on the floor of the facilities. Projectors are mounted on the AGVs at different heights; therefore the projected area varies. Data projected can represent the future path that the AGVs are going to follow by means of arrows (Fig. 4) and lines or only the occupied space (Matsumaru 2006, Coovert et al. 2014, Chadalavada et al. 2015).

Direction

Direction features are useful to understand in real time the direction of the end-effector. These features are commonly represented by 3D virtual



Augmented Reality for Human-Robot Interaction in Industry, Fig. 4 Example of AR contents used to display the AGV's path (yellow arrows) and the area that it will occupy (in blue). (Reproduced from RoboCup 2013 (CC BY 2.0))

arrows placed in the position of the end-effector (Fig. 5), and they are visualized in the real environment using wearable or handheld devices (Michalos et al. 2016).

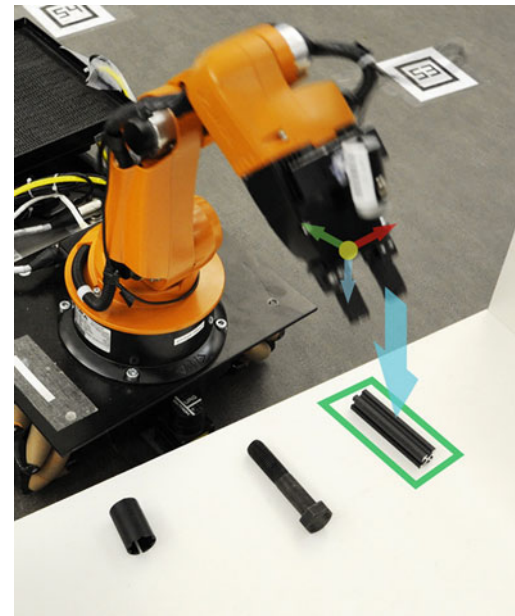
Object Manipulated

Objects that are going to be manipulated by the robotic arms can be highlighted using both 2D and 3D features. The 2D features are commonly represented by means of icons or geometric planar shapes projected directly on the object (Fig. 5). The projectors are mounted directly on the industrial manipulator or on appropriate supports placed near the robotic arm. The 3D features are commonly represented by 3D virtual replicas of the real objects that are superimposed on the object manipulated by the robotic arm (Akan and Çürüklü 2010).

Workspace

It is possible to identify two different workspaces: the first one is the workspace of a robot arm manipulator, defined as the set that comprehend all the positions it can reach; the second one is the "collaborative workspace," defined as the working area in which both the human operator and the industrial manipulator work together.

The robot workspace is commonly visualized using handheld or wearable devices. The operating area of the industrial manipulator can be represented using a 3D sphere, centered in the base of the industrial manipulator. The diameter of the sphere can also vary, depending on the movements of the end-effector.



Augmented Reality for Human-Robot Interaction in Industry, Fig. 5 Example of AR contents used to display the object to be manipulated (in green), the direction of the end-effector (in blue), and the forces on it (three axes on the end-effector). (Reproduced from RoboCup 2013 (CC BY 2.0))

The second workspace can be visualized using optical see-trough (Makris et al. 2017) or

projected AR systems (Vogel et al. 2011). Projectors are placed near the robotic arm, in an elevated position, and the "collaborative workspace" is projected directly on the floor. Optical see-trough systems are usually composed by cameras, placed in the corners of the environment. Depending on the distance of the user from the robot, at least two different areas are projected: the furthest area that is considered the safest operating area for the human worker, and it is commonly colored green and the closest area that is considered the most dangerous operating area for the human worker, and it is commonly colored red. When the human worker operates in the furthest area, the robotic arm works normally. On the other hand, when the human worker is in the closest area, the robotic arm stops or slows down its motion in order to avoid any possible damage (Fig. 6).

Augmented Reality for Human-Robot Interaction in Industry, Fig. 6 Example of AR contents used to display workspace of the robotic arm, with different colors depending on the safety for the user based on distance and arrows displaying the direction of the movement (in green) and an error state for one joint (in red). (Reproduced from Humanrobo 2009 (CC BY-SA 3.0))

Forces

Forces applied by the end-effector can be monitored and visualized using wearable or handheld devices. Forces can be represented using 3D virtual vectors, applied on the tool center (Fig. 4). The force components in X, Y, and Z are displayed as well as the resulting vector. Furthermore, the components are colored with different colors, depending on the intensity of the force (Mateo et al. 2014).

Faults

When a fault occurs on an industrial manipulator that is working side by side with a human operator, stress and anxiety may increase in the worker because he is not able to realize in real time which is the cause of the error. Moreover, since it is not possible to realize the cause of the fault immediately, the time and resources required to solve it strongly increase.

There are at least four different categories of faults that can be visualized using AR technologies: faults on the velocity sensor, faults on the actuation system, faults due to overloading problems, and faults caused by collision (De Pace et al. 2018). These typologies of errors can be visualized using both hand-handled and wearable devices. Each fault is represented using a specific 3D asset, superimposed on the error's location. Faults on the velocity sensors are represented using 3D circular arrows placed near the robotic arm's joints. These arrows rotate as long as the velocity sensor is acquiring correct data from the motor encoder (Fig. 6, green arrow). When a fault occurs on the velocity sensor, the arrows stop moving, and they change their color to red to highlight the problem (Fig. 6, red arrow). Faults on the actuation system can affect the joint's motor. If an error occurs on it, a 3D model representing the motor is superimposed on the real motor. Moreover, it starts blinking to emphasize the location of the fault. Faults due to collision can be represented using a 3D sphere center at the base of the industrial manipulator. A collaborative manipulator is able

to foresee collisions, and when it detects an unexpected object, it stops its movements to avoid the collision. Human operators may not understand why the manipulator has stopped its movements, misunderstanding its actions. To avoid these misjudgments, when the manipulator foresees the collision, the 3D sphere starts blinking to highlight the intentions of the industrial robotic arm. Finally, errors due to overloading problems suddenly stop the movements of the manipulator. When this type of fault occurs, a 3D anvil, along with a warning signal, is superimposed on the payload.

Cross-References

- ▶ Augmented Reality Entertainment: Taking Gaming Out of the Box
- ▶ Augmented Reality for Maintenance
- ▶ Augmented Reality in Image-Guided Surgery
- ▶ Conceptual Model of Mobile Augmented Reality for Cultural Heritage
- ▶ Integrating Virtual Reality and Augmented Reality into Advertising Campaigns: History, Technology, and Future Trends
- ▶ Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality
- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Interactive Augmented Reality to Support Education
- ▶ Mixed Reality
- ▶ Mixed Reality and Immersive Data Visualization
- ▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
- ▶ Potential of Augmented Reality for Intelligent Transportation Systems
- ▶ Training Spatial Skills with Virtual Reality and Augmented Reality

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Augmented Reality for Maintenance

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Synonyms

Mediated reality; Mixed reality; Real-time augmentation

Definition

Augmented reality for maintenance is a technologic solution encompassing both software and hardware resources with the aim of providing additional virtual information as a support for assisting technicians in performing complex tasks.

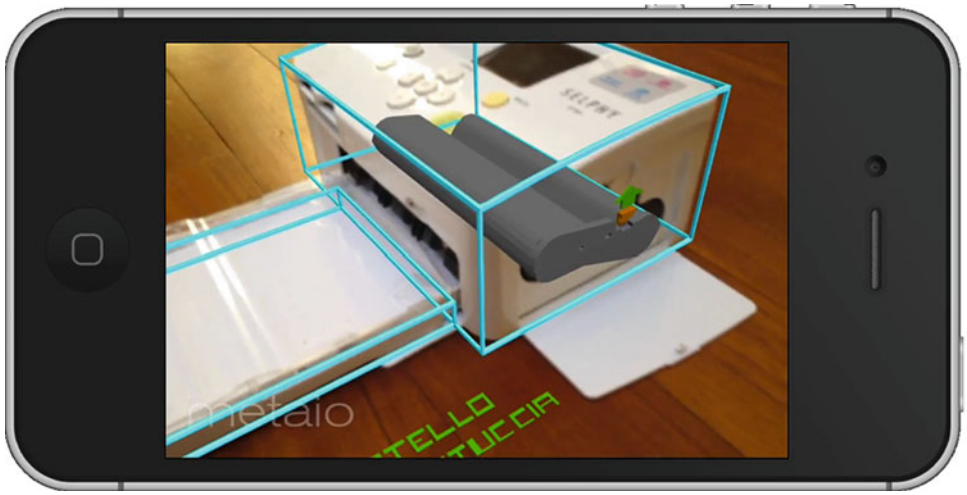
Introduction

Augmented reality (AR) is considered a computer vision solution aimed at "augmenting" the real world with additional information in the reality-virtuality continuum by Milgram and Kishino (1994). Differently from virtual reality (VR), where entire virtual reproductions of the real world are generated, in augmented reality the central idea is to add virtual objects (or overlay visual aids) into a real scene. Augmented scenes are conveyed to the user either in see-through head-mounted displays or in images captured by a camera. Computer vision algorithms have the key role of analyzing the images provided by the camera and solve the positioning and orientation problem of virtual objects within the real scene.

Augmented reality technology has been and is currently used in a wide range of application scenarios encompassing those concerning gaming, entertainment, cultural heritage, tourism, construction, education, health care, navigation, military, to name a few. Recently, this technology gained more interest also in industrial and manufacturing contexts due to the recent advances in the field. Indeed, even though maintenance, repair, and assembly are considered strategic application fields for augmented reality technologies from a couple of decades, only in recent times it has been possible to widen the development of related applications by focusing the efforts in the exploitation of consumer electronics devices. Previously, ad hoc hardware only used by specialists was developed and involved in limited experimental tests. Figure 1 shows an applicative use case which makes use of a consumer device (a smartphone or a tablet) to provide the user step-by-step instructions about the procedure for manual replacement of exhausted toner for a commercial printer. The application running on the handheld device recognizes the item subject to maintenance and provides contextualized hints by superimposing relevant animations to perform the replacement procedure.

The development of augmented reality applications in manufacturing processes represents the evolution of the industry in the digital era. Starting from seventeenth century, during the first industrial revolution, mechanical production systems as a substitute of hand production methods appeared for the first time in manufacturing processes. During the second industrial revolution, large-scale manufacturing of machine tools together with improvements in transports lead the industry to mass production methods. More recently, the introduction of information technology in the industry revolutionized again the manufacturing processes by pervading them with the digital transformation. For instance, programmable controllers and computer-based software applications added another dimension to the control capabilities of machine tools. The last epochal evolution in manufacturing concerns the switch from the introduction of information technology to the integration of cyber-physical systems, which is characterized by a higher degree of design complexity.

In this context, characterized by a trend in developing ever more complex manufacturing systems, all maintenance processes become ever more challenging, also for experienced operators.



Augmented Reality for Maintenance, Fig. 1 Augmented reality use case. Virtual animations are superimposed to the user's view through a mobile device to provide step-by-step instructions to replace internal components of a consumer device

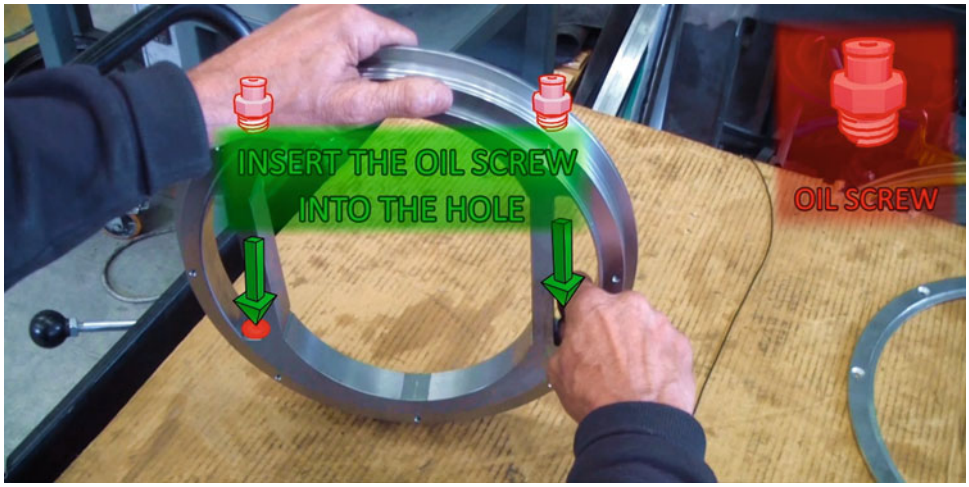
The variety of adopted industrial equipment and machinery are becoming more functionally rich. Indeed, new industrial technologies are characterized often by a combination of advanced electronics and software, thereby requiring operators to possess an in-depth knowledge which can be built only after years of work in their field. Additionally, it should be also taken into account that the fast pace of change in technology-related areas requires constant updates for the technical personnel. Often, even the more experienced operator has to deal with new situations to solve technical issues in complex cyber-physical systems. As a result, operational and functional failures are more difficult and expensive to detect, troubleshoot, and repair.

In this increasingly complex industrial machine scenario, augmented reality-based solutions aim to improve technician's performance by enabling intuitive representations and real-time visualization of relevant information regarding both corrective and predictive maintenance (Antonijević et al. 2016). Figures 2 and 3 show two applicative use cases of augmented reality in the field of maintenance in an industrial scenario, conceived in the EASE-R[12] European Project (http://www.easer3.eu/). In both cases, a technician is engaged in carrying out a specific maintenance procedure, i.e., the replacement of bearings in stone cutting machines in Fig. 2 and cleaning of lens in a laser-based precision measurement tool in Fig. 3. The illustrated use cases are representative of the main features belonging to augmented reality-based applications:

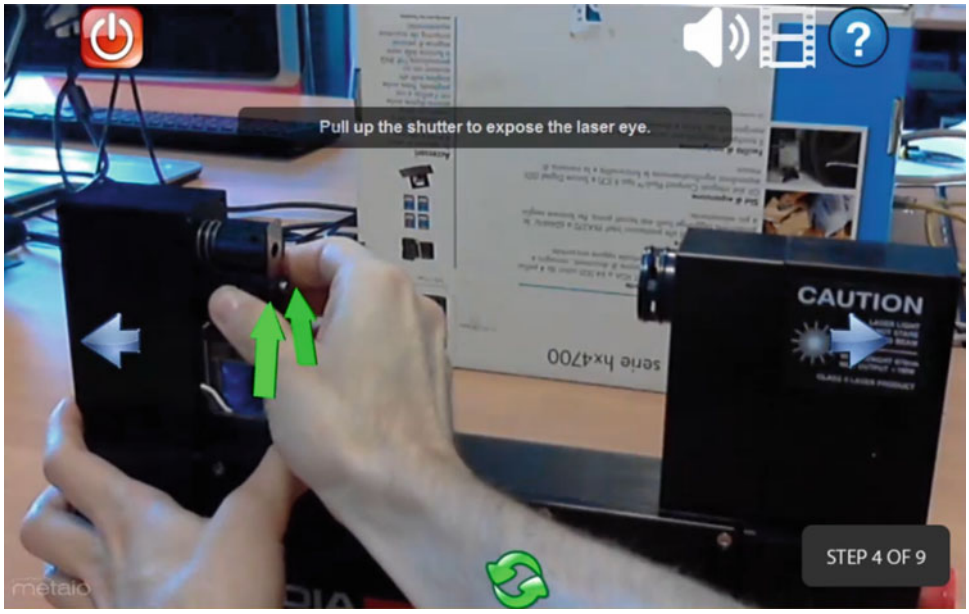
- The superimposition of virtual objects and hints onto the real world in real time
- The possibility to take into account of the user's viewpoint by means of a tracking system
- The possibility to insert virtual objects in a real world scene by automatically calculating all their 6 degrees of freedom (DOFs) which control the objects' location, orientation, and scale

Benefits of Using Augmented Reality in the Industry

Augmented reality gives the opportunity to make easier for industry workers to deal with specific industrial processes. Typical applications range from maintenance tasks, where specific and punctual information concerning cyber-physical systems are contextualized in real settings, to virtual engineering, where virtual prototypes constitute the basis for engineering tasks (Vilacoba et al. 2016).



Augmented Reality for Maintenance, Fig. 2 Augmented reality industrial use case concerning the replacement of bearings in stone cutting machines



Augmented Reality for Maintenance, Fig. 3 Augmented reality industrial use case concerning the cleaning of lens in a laser-based precision measurement tool

The most common application concern the transformation of conventional manuals into digital instructions – showing operations to be performed at the right time in the right place – which may have the characteristics of being always updated thanks to connectivity, thereby providing additional documentation available on demand and representing an effective tool for guided troubleshooting (Ghimire et al. 2016). Based on the situation faced by an operator, a visualization system – either in the form of hand-held devices (HHD) or head-mounted displays (HMD) – retrieve all necessary information and provides appropriate instructions back to the user

through the augmented reality display and other components (e.g., audio). Instructions can be of arbitrary choice, from simple reproduction of technical manuals, design diagrams, schematics to contextualized 3D static models, virtual animations, short movies, images, and audio instructions. Instructions are superimposed to the field of view of maintenance operators, which can safely work on faulty equipment.

Augmented reality can be seen as a methodology to provide just-in-time training, by delivering only the information needed in a particular context while performing a specific task. Technicians exploit this information to operate on the task and are able to increment their prior personal knowledge in a lifelong learning process. This way, they are also allowed to deal with an increased range of maintenance tasks than before with less training, which translates in evident advantages from the point of view of a more cost effective allocation of the workforce in the industry. In fact, in this scenario, a single operator is able to handle several equipment and customers' machineries, thus improving responsiveness and customer satisfaction.

It has been proven that augmented reality allows users to perform maintenance tasks with a lower rate of errors and faster than using paper-based instruction manuals (Lamberti et al. 2014, 2017; Henderson and Feiner 2011). This is due to an improved user experience driven by the fact that virtual tools can be directly shown in real working environments and real-time information is always available in the scene for the technician. It is worth recalling that faster intervention times at the factory floor reduces machinery downtime, thereby reducing loss of profits for an industry. Moreover, other key drivers for the adoption of these systems concern the reduction of technicians' mental workload during operations, the possibility to count on technical assistance during maintenance, and the reduction in training time for new technicians.

Trends and Challenges

To maximize the effectiveness and usability of augmented reality interfaces, their design should seamlessly integrate computer graphics with real environments by avoiding the use of encumbering technologies. Today, the majority of mobile augmented reality systems are based on head-mounted displays (HMDs) and see-through devices. HMDs involve the use of complex equipment to be worn by the user (e.g., the Oculus Rift). See-through systems became popular due to the rapid prototyping possibilities offered by several software libraries (e.g., ARToolkit). However, a current bottleneck is constituted by the use of transparent display technology, which is not mature yet.

There exist several options for overlapping digital contents to the surrounding world (Navab 2004):

- Projecting virtual models onto objects in the real world
- Integrating virtual models into camera views obtained from video cameras
- Projecting virtual components onto the user's retina
- Visualizing the virtual components through a semitransparent display while observing the real world

In industrial scenarios, the last two options should be preferred since they provide unhindered views while remaining safe and secure. In fact, portable and unobtrusive devices like see-through glasses guarantee hands-free operations by repair technicians.

Virtual retinal displays (VRDs) have been also recently introduced to overlay diagnostics and repair instructions directly onto the view of maintenance operators.

Whatever the technology used to visualize the augmented components, one of the key problems in augmented reality is the determination of the position and orientation of a camera in 3D space, known as camera pose estimation problem. It should be considered that the level of accuracy needed in pose estimation in augmented reality applications for maintenance is, in general, more demanding than in other fields. Indeed, small changes in a pose can be the cause of huge deviations in the visualization of the virtual content (Lakshmprabha et al. 2015).

The majority of augmented reality applications are based on the use of markers (like QR codes) to solve the real-time camera pose estimation problem (Antonijević et al. 2016). Marker-based techniques are particularly suitable for stationary objects. They require to modify the aspect of the real world manufacturing scenario by introducing specific markers on the top of machines or within the real environment to correctly locate virtual assets. Therefore, often the use of markers is perceived as a limitation of augmented reality (De Crescenzio et al. 2011). Marker-based techniques require that illumination is sufficient and markers are always visible.

On the other hand, marker-less techniques permit both to track moving parts and avoid the use of external markers to be placed in the environment (Lamberti et al. 2017). Marker-less techniques are based on image processing algorithms aimed to detect image features and perform 3D reconstruction. The process involves different phases, namely feature extraction, features detection, features matching, and image registration. The most promising algorithms used for feature extraction are Scale Invariant Feature Transform (SIFT) and Speed-Up Robust Features (SURF). Features detection algorithms apply classification mechanism like Support Vector Machine (SVM), K-Nearest Neighbor (KNN), and Sparse Representation-based Classification (SRC). Features matching, which consists in finding the correspondence between two set of features, can be achieved by applying the well-known k-d Tree algorithm. Finally, Image Registration concerns the calculation of the geometrical transform that aligns the featured points of two images of the same object. A suitable methodology is provided by random sample consensus (RANSAC) (Dandachi et al. 2015).

Given the overview of the algorithms used in augmented reality, a possible bottleneck concerns the need of sophisticated processing on devices that should be portable. The challenge is to develop solutions capable to take into account the currently achievable speed and accuracy. In fact, one of the issues with today's augmented reality applications is the lack of accuracy in 3D resolution (Vilacoba et al. 2016), which translates into a problem in precise positioning of virtual components.

Additional challenges are raised by the interaction paradigm needed for using the application effectively and in natural way. Though many augmented reality applications are developed just as an informative means (e.g., furniture placement in interior design), thus letting the interaction through touch-based screen devices be suitable for the specific task, the use cases which can be faced in manufacturing and industrial scenarios have different requirements in terms of interaction. In fact, technicians should carry out hands-free tasks. This requirement makes troublesome the use of input devices based on hand interaction, e.g., touch- and multitouch-based. A possible solution is related to the use of speech recognition technology, today enough mature to ensure an intuitive and natural user experience. Recent proposals in the field encompass also the possibility of automatically generating icon-based interfaces to associate unconstrained voice commands issued by the user to application functionalities based on the semantic similarity with the evoked command (Lamberti et al. 2017). However, it should be considered that speech recognition technology is robust in controlled situations, i.e., non-noisy environments. Thus, the noise at the factory floor should be taken into account in the design of an augmented reality solution. Gaze-based communication represents a possible alternative solution to the problem of hands-free interaction. Gaze recognition provides a thoughtful and natural interaction mode. On the other hand, special purpose hardware (i.e., infrared cameras) is needed to realize a robust gaze-based interface, which can be in competition with the hardware used for augmented reality (e.g., HMD and see-through glasses). Other possible solutions concern the use of gesture/pose recognition technologies, where the user could interact with the application interface both by using hand gestures/static poses (e.g., recognized through consumer devices such as the Leap Motion and Microsoft Kinect) and wearable solutions (e.g., inertial-based trackers) Henderson and Feiner (2010). However, in all these latter cases, the technician should suspend the maintenance procedure to interact with the application.

Conclusion and Discussion

Augmented reality domain can be applied in different application scenarios, encompassing gaming, entertainment, cultural heritage, tourism, construction, maintenance, education, health care, navigation, and military. Among them, industrial maintenance and repair represents a strategic thread for the application of augmented reality-related technologies, due to the economic revenues resulting from the possible reduction in time required for maintenance of complex systems and the automation of training processes. This entry described the benefits of using augmented reality technologies in the maintenance and repair field. Open issues are also discussed, mainly focusing on technological problems that currently limit a further spread of augmented reality solutions.

Cross-References

- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology

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Augmented Reality Gaming

▶ Augmented Reality Entertainment: Taking Gaming Out of the Box

Augmented Reality in Image-Guided Surgery

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Synonyms

Augmented reality in surgery; Image-guided surgery; Surgical navigation

Definition

Augmented reality visualization in image-guided surgery provides the surgeon with the ability to access the radiological images and surgical planning contextually to the anatomy of the real patient. It aims to integrate surgical navigation with virtual planning.

Introduction

The general ability to see into a living human system and to transfer the three-dimensional complexity of the human body into a comprehensive and useful visual representation has historically been considered of utmost importance by physicians in their will to pass on the acquired knowledge and experience to future generations (Fig. 1). In more recent times, the growing availability of new medical imaging modalities together with the need to reduce the invasiveness of the surgical procedures has encouraged the research for new 3D visualization modalities of patient-specific virtual reconstructions of the anatomy. Those visualization modalities have been designed to act as surgical guidance and as tools for surgical planning or for diagnosis (Peters 2000, 2006).

The idea of integrating in situ the surgeon's perceptive efficiency with the aid of new augmented reality (AR) visualization modalities has become a dominant topic of academic and industrial research in the medical domain since the 1990s. The high expectations accrued among researchers, technicians, and physicians regarding this fascinating new technology were predominantly related to the improvements potentially brought by AR-based devices to surgical navigation and planning. In this context, AR visualization is indeed regarded as capable of providing the surgeon with the ability to access the radiological images and surgical planning contextually to the real patient anatomy.

Consequently, in image-guided surgery (IGS) systems, AR technology appears as a significant development, because it aims to profitably integrate surgical navigation with virtual planning (Kersten-Oertel et al. 2013).

Augmented Reality in Image-Guided Surgery, Fig. 1 Pictorial representation of the th7ree-dimensional complexity of the human anatomy (Frans Denys, The Anatomy Lesson of Dr. Joannes van Buyten, 1648, oil on canvas)

State-of-the-Art Work

Background

In 1986 (Roberts et al. 1986) a first implementation of a medical AR neurosurgical guidance system was proposed: the system was intended to allow the proper projection of computed tomography (CT) image data into the optics of an operating microscope. After an interactive patient-to-CT image registration, an ultrasonic non-real-time tracking of the microscope allowed proper reformatting of the CT data before being projected into the eyepieces of the microscope. Since then, tools (or defined applications) employing AR have been designed and tested in the context of several surgical and medical disciplines (Rankin et al. 2015). These applications comprise video see-through systems (in conjunction with standard workstations, laptops, and tablet PC), modified endoscopes, and modified operating microscopes. AR has been proposed in many surgical contexts, including maxillofacial surgery (Marmulla et al. 2005; Zinser et al. 2013b; Badiali et al. 2014; Suenaga et al. 2015; Wang et al. 2017; Zhu et al. 2017), neurosurgery (Edwards et al. 2004; Lovo et al. 2007; Low et al. 2010; Inoue et al. 2013; Cabrilo et al. 2014, 2015; Kersten-Oertel et al. 2015; Meola et al. 2016; Cutolo et al. 2017), ENT (ear, nose, and throat) surgery (Caversaccio et al. 2008), orthopedic surgery (Navab et al. 2010; Abe et al. 2013; Wu et al. 2014; Fritz et al. 2014; Cutolo et al. 2016a; Elmi-Terander et al. 2016), robotic surgery (Falk et al. 2005; Su et al. 2009; Zeng et al. 2017), and general/laparoscopic surgery (Feuerstein et al. 2008; Baumhauer et al. 2007; Nicolau et al. 2011; Muller et al. 2013).

Open Issues

Despite such widespread diffusion, there are still major reasons why AR IGS systems are not yet routinely used in the medical workflow. Among them, there is the fact that most of the systems were historically, and still are, developed as proof-of-concept devices that were/are mostly conceived for research users more than for their immediate translation into immediate and reliable applications.

Many of those systems did not take into account the operational constraints imposed by the surgical context and did not satisfy the surgeons' practical needs and requirements. Generally, many AR systems have been regarded as disrupting the surgeon's act primarily because most of them have lacked of a systematic evaluation within a clinical context (Kersten-Oertel et al. 2012; Meola et al. 2016). In fact, the basic condition for the acceptance of a new technology (as AR) in the operating room (OR) is related to its capacity of being smoothly integrated into the workflow of the intervention, without affecting and disturbing the user during the rest of the procedure (Navab et al. 2007; Sielhorst et al. 2008).

Despite all of this, with the advances in technology, AR will surely soon represent a leading-edge solution in the context of IGS, especially once the balance between technological expectations and realistic and application-driven outcomes will be achieved.

Taxonomy for Classification

In 2012, a taxonomy of AR visualization systems in IGS was proposed (Kersten-Oertel et al. 2012), and a systematic overview of the trends and solutions adopted in the field to that day presented (Kersten-Oertel et al. 2013). The acronym for the taxonomy (DVV) is derived from its three key components: data type, visualization processing, and view. According to the taxonomy, for classifying and assessing the efficacy of a new AR system for IGS, the attention ought to be focused on the particular surgical scenario in which the visualization system aims to be integrated.

The surgical scenario affects each of the three DVV factors, namely, the type of data that should be displayed at a specific surgical step, the visualization processing technique implemented to provide the best pictorial representation of the augmented scene, and how and where the output of the visualization processing should be presented to the end user (i.e., the view).

Different AR Display Units in IGS

In the realm of AR-based IGS systems, different technological approaches and specifically different embodiments of the display units have been proposed, each with its own advantages and drawbacks. In Table 1 advantages and drawbacks of different AR-based solutions are reported. In the light of avoiding abrupt changes to the surgical setup and workflow, historically the first AR-based systems in surgical navigation have been implemented starting from commonly used devices. Augmented operating microscopes were proposed in neurosurgery and in maxillofacial surgery (Birkfellner et al. 2002). In these systems, generally the augmentation happens by "injecting" the virtual content directly into the optical path of the real image, hence by inserting a beam splitter into the microscope optics. The fixed configuration of the eyepieces with respect to the surgical scene makes them not usable with different viewpoints.

Other solutions featured the use of spatial monitors and video-based tracking modalities and were used in neurosurgery (Grimson et al. 1996; Deng et al. 2014), maxillofacial surgery (Zinser et al. 2013a), and general surgery (Muller et al. 2013). Such systems, as the ones based on external monitors, have a reduced logistic impact within the operating room, but they do not provide an egocentric viewpoint of the surgical scene.

Another category of AR systems was based on the use of half-transparent screens in conjunction with display technologies providing monoscopic, stereoscopic, or autostereoscopic parallax. Blackwell (Blackwelll et al. 1998) and Wesarg (Wesarg et al. 2004) introduced two different prototypes of AR windows. The first system by Blackwell provided a stereoscopic vision of the virtual content by means of a pair of shutter glasses, whereas the second one by Wesarg was monoscopic. Stetten et al. (2001) have proposed a simple and interesting optical see-through handheld half-silvered mirror that overlays ultrasound scans aligned with the scanned area.

The major shortcomings of the optical see-through paradigm implemented in standard AR windows are due to the intrinsic incompatibility between the 3D representation of the real world and the nature of the virtual content, rendered as a 2D image. This causes few perceptual conflicts in depth perception. To cope with these issues, alternative and promising approaches, based on the integral imaging technology, were proposed (Liao et al. 2001, 2004). Integral imaging displays use a set of 2D elemental images from different perspectives to generate a full-parallax 3D visualization. Therefore, with integral imaging-based displays, a proper 3D overlay between virtual content and real scene can be obtained. Some embodiments of such technology have been specifically designed and tested for maxillofacial surgery and neurosurgery (Iseki et al. 1997; Narita et al. 2014; Liao et al. 2006, 2010; Suenaga et al. 2013). The integral imaging paradigm thus is able to provide the user with an egocentric viewpoint and a full-parallax augmented view in a limited viewing zone (imposed by the integral imaging display).

In laparoscopy, and generally in endoscopic surgery, the part of the environment where the attention of the surgeon is focused during the surgical task (DVV's perception location) is a stand-up monitor. Indeed, in such procedures, the surgeon operates watching endoscopic video images reproduced on the spatial display unit (Caversaccio et al. 2008; Freysinger et al. 1997). Therefore, the virtual information is usually merged with the real-time video frames grabbed by the endoscope and presented on a stand-up monitor. These systems were also tested in robotic surgery (Su et al. 2009; Mourgues and Coste-Maniere 2002; Devernay et al. 2001). Particularly in IGS, the quality of an augmented reality (AR) experience depends on how well the virtual content is integrated into the real world spatially, photometrically, and temporally (Sielhorst et al. 2008). For this reason, wearable AR systems particularly offer the most ergonomic solution in those medical tasks manually performed under user's direct vision (open surgery, introduction of biopsy needle, palpation, etc.) since they minimize the extra mental effort normally required for switching the attention between the surgical area and the augmented view presented on the external display.

Augmented Reality in Image-Guided Surgery, Table 1 Different embodiments of AR displays for IGS

AR display type	Advantages	Drawbacks
Surgical microscope	Surgical microscopes are already routinely used in several microsurgical procedures	Bulkiness
	Fixed configuration: degradation of the calibration is decreased	Fixed configuration: not adaptable to comply with different viewpoints
Video see-through handheld displays (tablet-smartphones)	Reduced logistic impact	Parallax problem (non-egocentric viewpoint)
		No stereopsis. Other depth cues are needed for depth perception
	Accurate image registration – no eye-to-display calibration is needed	Difficult to use in those surgical tasks manually performed under surgeon's direct vision
		Peripheral view not registered with AR view
		Camera-mediated view of the surgical area
Optical see-through external screens (stereoscopic and monoscopic)	Direct view of the surgical area	AR image registration is not so accurate: robust and reliable eye-to-display calibration would be needed
		Display brightness may not be sufficient under scialytic lamps
		Perceptual conflicts due to mismatched accommodations between real scene and virtual content
		Parallax problem (non-egocentric viewpoint)
		Difficult to use in those surgical tasks manually performed under surgeon's direct vision
Video see-through external displays	External monitors are already present in the surgical rooms	Parallax problem (non-egocentric viewpoint)
		Mostly 2D displays: no stereopsis
	Accurate image registration – no eye-to-display calibration is needed	Difficult to use in those surgical tasks manually performed under surgeon's direct vision
		Camera-mediated view of the surgical area
Full-parallax 3D displays	Full-parallax view of the scene. Natural depth perception is recovered	Bulkiness
	Accurate image registration – no eye-to-display calibration is needed	Limited depth range
		Limited resolution and limited viewing zone
Optical see-through wearable displays (monoscopic or stereoscopic)	Egocentric viewpoint	Perceptual conflicts due to mismatched accommodations between real scene and virtual content
	Reduced logistic impact	AR image registration is not so accurate: robust and reliable eye-to-display calibration would be needed
		Display brightness may not be sufficient under scialytic lamps
Video see-through wearable displays (monoscopic or stereoscopic)	Egocentric viewpoint	Perceptual vergence-accommodation conflict
		Restricted peripheral view
	Accurate image registration – no eye-to-display calibration is needed	Surgeon's field of view is restricted by the display
	Reduced logistic impact	Camera-mediated view of the surgical area

Wearable AR Displays in IGS

Wearable AR systems based on HMDs intrinsically provide the user with an egocentric viewpoint, and by generating both binocular parallax and motion parallax, they smoothly augment the user's perception of the surgical scene (Cutolo et al. 2016b). In these HMDs, the see-through capability is accomplished either through the aforementioned video see-through paradigm or through the optical see-through paradigm.

Typically, in optical see-through systems, the user's direct view of the real world is augmented with the projection of virtual information on a beam combiner and then into the user's line of sight (Rolland et al. 1994). Differently, in video see-through systems, the virtual content is merged with camera images captured by two external cameras rigidly fixed on the visor.

The industrial pioneers, as well as the early adopters of AR technology, properly considered the camera-mediated view typical of the video see-through paradigm, as drastically affecting the quality of the visual perception and experience of the real world. By contrast, optical see-through systems provide the user with a natural view of the real world with full resolution. The fundamental optical see-through paradigm of HMDs is still the same as described by Benton (Benton 2001). A straightforward implementation of the optical see-through paradigm comprises the employment of a half-silvered mirror or beam combiner to merge real view and virtual content. The user's own view is herein augmented by rendering the virtual content on a two-dimensional (2D) microdisplay and by sending it to the beam combiner. Lenses can be placed between the beam combiner and the display to focus the virtual 2D image so that it appears at a comfortable viewing distance on a semitransparent surface of projection (SSP) (Rolland and Cakmakci 2005; Holliman et al. 2011). As an alternative, the use of high-precision waveguide technologies allows the removal of the bulky optical engine placed in front of the eyes (Mukawa et al. 2008). The optical see-through paradigm is particularly suitable for augmenting the reality by means of simple virtual elements (models, icons, or text labels), but shortcomings remain both from a technical and a perceptual standpoint, especially in case of virtual contents of greater complexity.

Although the optical see-through HMDs were once at the leading edge of the AR research, their degree of adoption and diffusion did slow down over the years due to technological and human-factor limitations. Just to mention a few of them: the presence of a small augmentable field of view, the reduced brightness offered by standard LCOS microdisplays, the perceptual conflicts between the 3D real-world and the 2D virtual image on the SSP, and the need for frequent recalibrations of the HMD for yielding accurate spatial registration. Some of the technological limitations, like the small field, are being and will be likely solved along with the technological progress. The remaining two limitations are harder to cope with.

The difference in the user's perception of the real 3D world and of the 2D projection of the virtual content on the SSP creates perceptual conflicts due to mismatched accommodations. These perceptual conflicts often are reflected in reducing the benefits brought by the optical paradigm of leaving unaltered the user's view of the real world. In optical see-through HMDs, the user is indeed forced to accommodate his/her eye for focusing all the virtual objects on the SSP placed at a fixed distance. On the other hand, the focus distance of each physical object in the 3D world depends on its relative distance from the observer and may dynamically vary over time. This means that even if an accurate geometric registration of virtual objects to the real scene is attained on the 2D SSP plane, the user may not be able to view both the virtual and real content in focus at the same time. This aspect is particularly relevant in applications devoted to surgical navigation, since it reduces the user's capacity to interact with the real surgical field while maintaining the virtual aid in focus. The second major shortcoming of the standard optical see-through HMDs is related with the geometric registration required to obtain a geometrically consistent augmentation of the

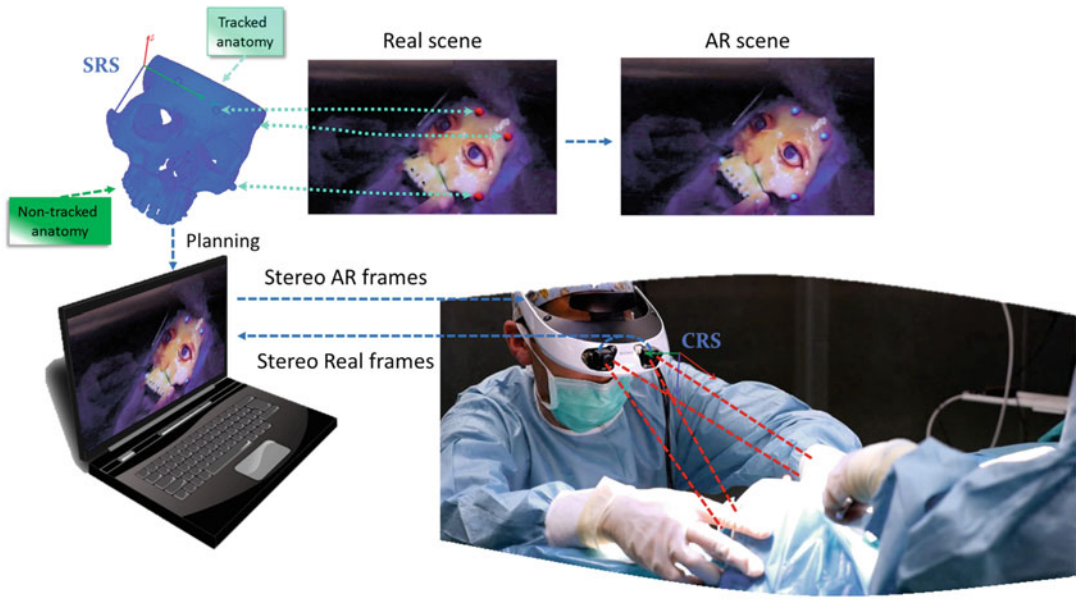
reality, which is an essential prerequisite for being considered as reliable surgical guidance system.

As a general rule, for obtaining accurate geometric registration in AR applications, the process of image formation generated by the virtual viewpoint must perfectly mimic, both intrinsically and extrinsically, the one of the real viewpoint (Cutolo et al. 2014). In optical see-through HMDs, the spatial alignment of the virtual content with the real 3D world needs for:

(a) The tracking of the HMD SSP in relation to the reference system of the real world (SRS)
(b) A user-specific calibration for estimating the pose between HMD SSP and user's eye (i.e., extrinsic calibration)
(c) The definition of a projective model of the virtual viewpoint that is consistent to the human eye projective model (i.e., intrinsic calibration)

State-of-the-art methods for tracking the HMDs (a) yield accurate results in terms of HMD pose estimation, whether they exploit external trackers or not. Differently, the calibration step needed to estimate user's eye pose in relation to the SSP reference system (b) often entails a tedious and error-prone method (Tuceryan et al. 2002; Genc et al. 2002; Gilson et al. 2008; Kellner et al. 2012). Further, this process should be repeated any time the HMD moves with respect to the user's eyes causing a change in the relative position between DRS and user's eye reference system, and it should be autonomous and real time. Current and more advanced calibration methods (Plopski et al. 2015, 2016), even if they work in real time, do not incorporate the user-specific and real-time estimation of the eye projective model (c), which can change over time with the focus distance due to the accommodation process.

Differently, the pixel-wise video-mixing technology that underpins the video see-through paradigm, once integrated with monocular or binocular HMDs, can offer high geometric coherence between virtual and real content. In these systems, a user-specific calibration routine is not necessary, and this is the major advantage of the video versus the optical see-through approach. In video see-through systems, real scene and virtual information



Augmented Reality in Image-Guided Surgery, Fig. 2 Video see-through paradigm of the stereoscopic HMD used to aid maxillary repositioning (Cutolo et al. 2015)

can be synchronized, whereas in optical see-through devices, there is an intrinsic lag between the immediate perception of the real scene and the inclusion of the virtual elements. Further, from a perceptual viewpoint, in video see-through systems, the visual experience of both the real and virtual content is unambiguously controllable by computer graphics, with everything on focus at the same apparent distance from the user. Additionally, video see-through systems are much more suited than optical see-through systems, to rendering occlusions between real and virtual elements or to implementing complex visualization processing modalities. Unfortunately, the loss of the unobstructed real-world view and the limited field of view of the displays embedded in commercial 3D visors are still the major drawbacks of the video see-through HMDs (Fig. 2). This aspect is of particular importance in IGS applications, wherever our goal is of trying to mimic the perceptive efficiency of the human visual system to allow a smoother interaction with the augmented visual information (Cutolo et al. 2015).

Conclusions and Future Goals

In recent times, the emerging of modern medical imaging technologies together with the need to reduce the invasiveness of the surgical procedures has encouraged the research for new 3D visualization modalities that could act as tools for surgical guidance. Current limits of standard IGS systems are mainly due to the increase of the surgical time needed for system setup and management and to the increase of technical complexity in the surgical workflow.

It was thus clear from the outset that, in this context, AR technology could have represented a groundbreaking development, because its primary goal is to integrate surgical navigation with virtual planning contextually to the real patient's anatomy.

AR technology can in fact provide the surgeon with a direct perception of where the virtual content is located within the surgical field, wherever the virtual content is generally obtained during preoperative planning.

In the ideal AR system, especially if designed for aiding complex operations that demand great dexterity as the ones pertaining to surgical procedures, there should not be any perceivable difference between the user's natural view of the world and his/her augmented view through the device display. For this goal, the conditions to be satisfied are twofold: accurate registration and ergonomic interaction.

In practical terms, if a new AR system for IGS were to comprise tedious calibration routines, the introduction of obtrusive instrumentation into the OR, and the presentation of complex and confounding computer-generated content and furthermore it were to bring questionable benefits to the surgical procedure, then it would be likely refused. Hence, to facilitate the accomplishment of such ambitious goals in the near future, researchers and early adopters ought to actively collaborate with physicians so that AR-based IGS systems could smoothly and profitably get into the surgical workflow.

Cross-References

- ▶ Augmented Learning Experience for School Education
- ▶ Augmented Reality Entertainment: Taking Gaming Out of the Box
- ▶ Augmented Reality for Maintenance

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Augmented Reality in Surgery

▶ Augmented Reality in Image-Guided Surgery

Augmented Reality Ludo Board Game with Q-Learning on Handheld

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Synonyms

3D board game; Augmented reality; Ludo game

Definition

An autonomous agent works with artificial intelligence (AI) to decide its actions to adapt and respond to the changes in a dynamic environment. The autonomous agent can be developed in games as a non-player character to interact with the changes of state in the game environment. Traditional board games such as Ludo have had many players since olden days but have slowly lost attraction to the public, especially the younger generations, as digital games become more popular. Although the Ludo board game can be digitized to fascinate the players through implementing augmented reality (AR) technology on handheld devices, common NPCs found in games have predetermined actions and are unable to learn from experience and adapt to the changes in the game environment. AR Ludo board game with Q-learning applied in handheld.

Introduction

Board games have appeared since ancient times with a lot of experienced players (ChePa et al. 2014). An example of a popular traditional board game is Ludo (Singh et al. 2019). However, the number of traditional board game players has declined since the appearance of digital games (Rizov et al. 2019). Hence, the Ludo board game can be digitized to retain the existing players while attracting new players.

Augmented reality (AR) is a technology that combines the real environment with the virtual environment or objects created by a computer (Tan and Soh 2011). This technology is added to a board game to further enhance the gaming experience (Rizov et al. 2019). Nowadays, AR technology is widely used in handheld devices such as smartphones that are equipped with advanced features (Zsila et al. 2018). Sensors that can be used to capture image, movement, and touch are equipped by the handheld devices (Grandi et al. 2018) as the rise of the devices' computational power (Sanches et al. 2019).

An autonomous agent is an agent that can decide to perform an action by itself in a given environment (Coutinho et al. 2015). The development of an autonomous agent is often tightly linked to artificial intelligence (AI), especially on decision-making (Moharir et al. 2019). In games, a non-player character (NPC) can act as an autonomous agent (Feng and Tan 2016). Common NPCs found in games are usually scripted with specific actions and are unable to learn from previous actions and adapt to a dynamic environment (Lim et al. 2012). Hence, the autonomous agent can be developed in a game through a machine learning algorithm to adapt to the changes in the environment, besides increasing the difficulty of the game and making it enjoyable (Feng and Tan 2016). Q-learning is an example of a reinforcement learning algorithm under machine learning that allows the agent to explore the environment and learn the best action in a specific state (Lee et al. 2017). The Q-learning algorithm is commonly used in a dynamic environment that involves one or multiple players [13]. Hence, the autonomous agent that works with the Q-learning algorithm can be developed for the AR Ludo board game.

AR is defined as a technology that combines real and virtual contents in the physical environment (Tan and Soh 2011). This technology overlays

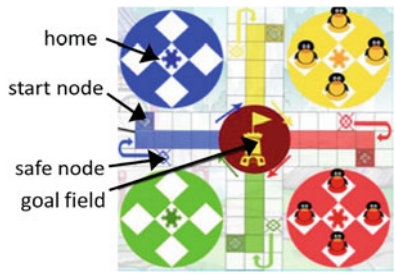
digital data on the real environment to present various information such as text or images [14]. An AR system focuses on four domains: sensing, tracking, interaction, and display [15]. An example of a tracking technique is feature-based tracking provided by Vuforia Engine to detect, identify, and track targets such as images or three-dimensional (3D) objects [16]. According to [17], Vuforia analyzes and detects the features of an image uploaded by a user. The more features detected in an image, the more suitable it is to be used as the image target. The analyzed result is represented through a star rating range from 0 to 5. The highest rating indicates that it is the easiest for Vuforia to track the image target.

Ludo Board Game

A board game is defined as a game that involves a board that allows pieces to move on top of it [18]. According to (Singh et al. 2019), the Ludo board game involves 2–4 players taking turns to roll a dice and move the tokens on the Ludo board. Figure 1 shows the Ludo board game.

The rules for the Ludo board game, as in Fig. 1, are based on [19]:

- At the beginning of the game, the players take turns to roll the dice and a player that rolls a six can move a token to the start node. Each player has four tokens at the beginning of the game.
- The players can only move a token according to the number rolled if the token is not at the home.
- Once a player rolls a six, that player can take another turn.



Augmented Reality Ludo Board Game with Q-Learning on Handheld, Fig. 1 Ludo board game [19]

- If a player moves a token to the place that is occupied by the opponent's token, the opponent's token is kicked and returned to his home.
- A token is safe from being kicked back to home once it lands on the safe square. Each player's start node is also considered as a safe square.
- The game ends once all the tokens of a player have landed on the goal field.

The development of autonomous Agent A starts with designing an algorithm based on Q-learning as in Fig. 2. Based on Fig. 2, the algorithm starts from initialization of the values in the Q-table to zero. After Agent A takes a turn to roll the dice, Agent A can select a random action through exploration or choose a greedy action through exploitation based on the epsilon-greedy (ε-greedy) policy. A greedy action is an action with the highest value in the Q-table at the given state. The epsilon value, ε, is declared as 1.0 at the beginning and continuously decreases for each action taken by Agent A. Random action is taken if the randomly generated value ranges from 0 to 1 is smaller than ε; otherwise, the greedy action is taken. The reward, r, is then measured based on the state-action pair taken. Bellman equation, $Q(s,a) = Q(s,a) + \alpha\,[r + \gamma\,[\![\max]\!]_{(a^{\wedge\prime} \in A)}\, Q(s^{\wedge\prime},a^{\wedge\prime}) - Q(s,a)]$, is used to update the value of the state-action pair taken in the Q-table. The learning rate, α, and discount factor, γ, are set as 0.7 and 0.1, respectively. These steps are repeated until the end of an episode. The training session is set up for Agent A with 20 episodes. An episode is ended once all the four tokens of a player have successfully moved into the goal field.

AR Ludo: Augmented Reality Ludo Board Game

The Ludo board game consists of a dice and four sets of tokens to match the four different colors of the home at each corner on the board. However, only two sets of tokens are used for the AR Ludo board game, as the game is limited to two players.

Augmented Reality Ludo Board Game with Q-Learning on Handheld, Fig. 2 Q-learning algorithm in Ludo board game

Initialize Q(s, a), $\forall s \in S, \forall a \in A$

For episode = 1,2,3…do

Repeat

Roll dice

For each token of the player

Initialize current state, *s*

Store s in the array

Initialize action, *a* based on the state and dice number

Store *a* in the array

End For

Choose action, *a* using epsilon-greedy policy:

If a random value < epsilon, ε

Then choose a random action, a

Else

Choose an action, a with highest Q(s,a) value

Take action, *a*

Observe reward, r and next state, s'

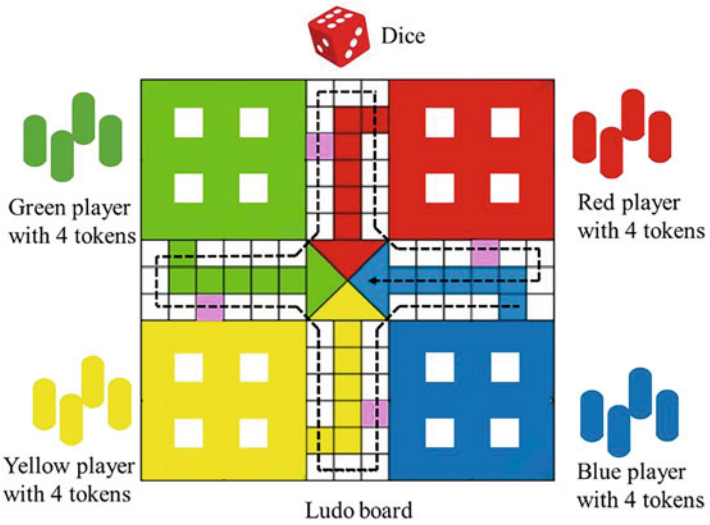
Update Q-table with Bellman equation

$$Q(s,a) = Q(s,a) + \alpha\,[r + \gamma\, max_{a' \in A} Q(s',a') - Q(s,a)]$$

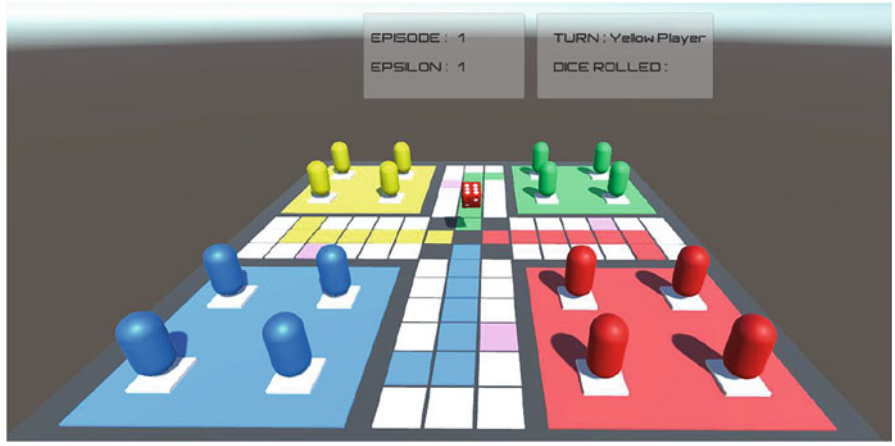
Until *s* is terminal // 4 tokens of a player reach goal field

End For

Augmented Reality Ludo Board Game with Q-Learning on Handheld, Fig. 3 AR Ludo game design



At the beginning of the game, one player is assigned with the four blue color tokens; meanwhile, the opponent player is assigned with the four green color tokens. Each player's four tokens are placed in the home. Next, each player takes a turn to roll the dice to move a token from the start node into the goal field. The goal of the game is to move all the four tokens into the goal field located



Augmented Reality Ludo Board Game with Q-Learning on Handheld, Fig. 4 Virtual Ludo game with Q-learning algorithm

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	Out Home	Get Into Goal	Move To Last Track	Move To Safe Square	Kill Opponent	Just Move
In Home	0.56337	0	0	0	0	0
On Last Track	0	1.035681	0.671286	0	0	0
On Safe Square	0	0	0.7215118	0.06530653	0.6852753	-0.1390742
On Free Space	0	0.9216789	0.7854184	0.4650407	0.6144565	-1.482576
In Goal	0	0	0	0	0	0

Augmented Reality Ludo Board Game with Q-Learning on Handheld, Fig. 5 Data stores for Q-learning

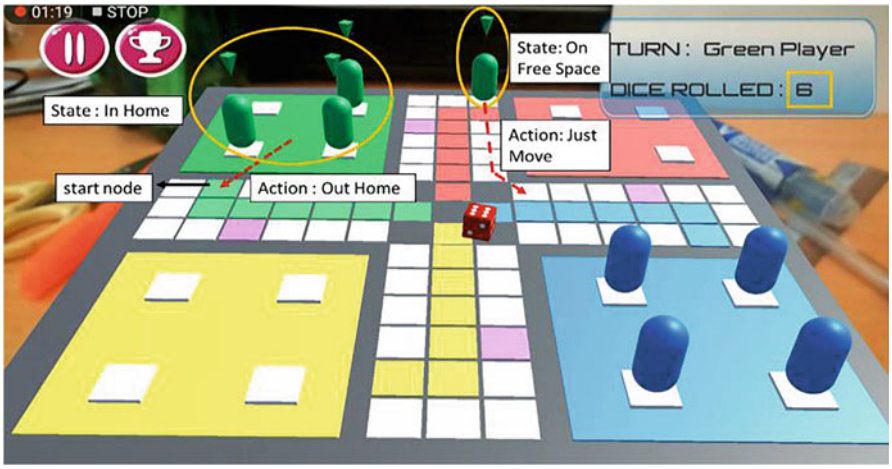
at the center of the board to win the game. Based on Fig. 3, there are four purple color nodes on the board called safe nodes and the dotted line shows an example of a blue tokens' path from the start node towards the goal field.

In order to implement the AR tracking in a handheld device, the Vuforia AR software development toolkit (SDK) is integrated with Unity3D software to track and compare the features of the marker with the target resource database. A PNG image based on the design of the Ludo board in RGB is uploaded to Vuforia Target Manager. This image is transformed into grayscale and the features extracted are collected and stored in the database. The virtual AR Ludo board game is displayed once the marker is detected and the marker's features match with the data stored in the database. The AR Ludo includes badges as a gamification element to reward the players. Feature-based tracking is chosen for AR Ludo in handheld focuses on Android mobile phones. The users can interact with the application through touch-based interaction on the mobile screen using a one-finger gesture.

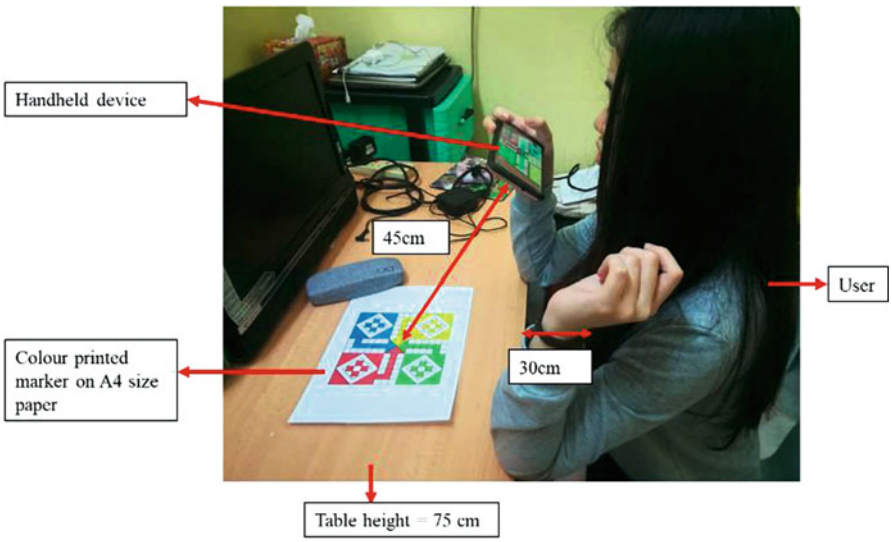
The designed Q-learning algorithm has been implemented in order to generate the optimal values in the Q-table, a training with 20 episodes is conducted between Q-learning agent (Agent A) and AR random players, and Agent A is assigned with the green color tokens. The other three random players take random actions to move in the game while training. Figure 4 shows the Ludo board game training environment performed on the Windows platform using Unity3D. The game environment is reset before starting a new episode after each episode ends.

At the end of the training, an output file that includes the finalized values of the Q-table is generated as in Fig. 5. Based on Fig. 5, the rows represent the states; meanwhile, the columns represent the actions.

An example is shown in Fig. 6 where the tokens inside the home have the state "In Home" and the action of moving a token to the start node from the home is "Out Home." A token placed on



Augmented Reality Ludo Board Game with Q-Learning on Handheld, Fig. 6 Tokens with the state "In Home" and action "Out Home" or state "On Free Space" and action "Just Move"

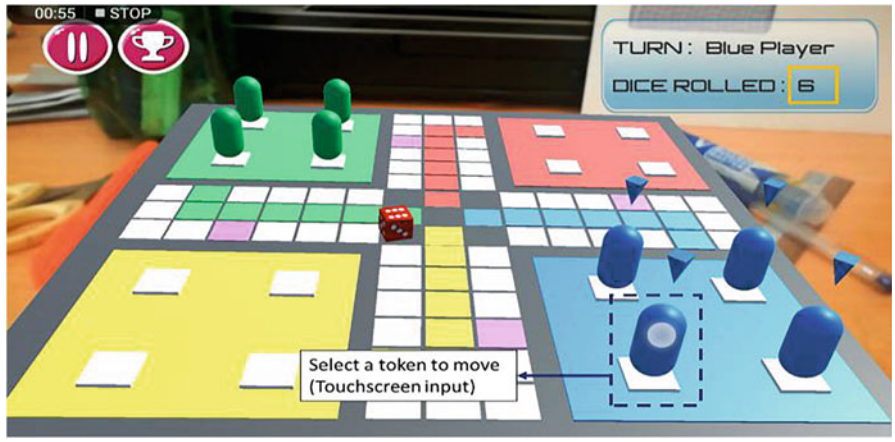


Augmented Reality Ludo Board Game with Q-Learning on Handheld, Fig. 7 User plays AR Ludo to against the Q-learning agent

a white node that surrounds the board has the state "On Free Space" and the action of moving a token from a white node to another without any opponent's token landed on it is "Just Move." Based on Fig. 6, Agent A can choose to move a token six steps forward or move a token out from home while a six is rolled. Agent A decides to move a token out of home as the value in the Q-table for this state-action is approximately 0.563 that is higher than the action "Just Move" at the state "On Free Space" with a value of approximately −1.483 based on Fig. 5.

AR Ludo on Handheld

The setup as in Fig. 7 is that the AR marker is color printed on an A4 size paper and placed on the table with a height of approximately 75 cm. The user sits approximately 30 cm in front of the



Augmented Reality Ludo Board Game with Q-Learning on Handheld, Fig. 8 AR Ludo board game on handheld

table with one hand holding the handheld device and the other hand interacting with the AR Ludo board game through touchscreen input. The handheld device with a camera used to track and display the AR Ludo board game is approximately 45 cm away from the marker.

The 3D Ludo board is developed with numerous cubes scaled in different sizes and colors of material. Each corner of the Ludo board has different colors, either yellow, blue, green, or red to represent each player's home. There are four purple color nodes that represent the safe nodes on the Ludo board, and each player's start node is set as the node that is nearest to the home with the same color. A token is created using a capsule, a 3D game object provided in Unity3D. In order to show a token can interact, an arrow model is imported into Unity3D to attach with the capsule. The dice model is also imported into the game. The UI of the AR Ludo board game is developed with buttons, checkboxes, and panels for interaction. The AR tracking is also enabled in handheld.

The AR Ludo board game allows the human player to play with the opponent player, Agent A. The human player is represented as the blue color tokens; meanwhile, the Agent A is represented as the green color tokens. On a human player's turn, the player can select the dice to roll or select a token to move as in Fig. 8 by touchscreen input after rolling a six.

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Augmented Virtuality

▶ Mixed Reality
▶ Virtual Reality and Robotics

Auralization

▶ Sound Spatialization

Autism

▶ Computer Games for People with Disability

Automated Game Design Testing Using Machine Learning

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Synonyms

Game Design Evaluating Using Machine Learning

Definitions

EA	Electronic Arts
NFT	Non-Fungible Tokens
CEO	Chief Executive Officer
MMO	Massively Multiplayer Online Game
Game	

Introduction

Games design is the field of study and practice of improving and measuring the structure and systems found within an analogue or digital game. The process of improving a game throughout the development and lifecycle of a game is key to the survival of the game. Notable examples include changes found within the rules of chess throughout its long lifespan and different iterations and versions of the game (Murray 2015). Game designers incrementally change the game to provide better entertainment to its participating players. Game designer and developer Robert Zubek defines game design by breaking it down into its elements, which he says are the following (Zubek 2020):

- Gameplay, which is the interaction between the player and the mechanics and systems
- Mechanics and systems, which are the rules and objects in the game
- Player experience, which is how users feel when they are playing the game

Improving a game design can be achieved through the use of analytical or experimental processes.

Paper Overview

This paper focusses on the different strategies and examples of the use of deep learning techniques when testing game design. This focusses on two aspects. A suitable use case of player replacements is to simulate experimental game design approaches such as automated play testing and content evaluation. Furthermore, this paper concludes with a brief summary of research measuring sentiment toward automated

game design testing processes by industry stakeholders.

Types of Game Design Techniques

Both analytical and experimental game design processes are resource intensive through the required analysis and participation of the player within the design process. Game publishers and academics have numerous testing approaches to accelerate the creation of games and improve the quality of their design in each part of the game lifecycle. Early attempts showed how games are controlled by procedural code such as behavior trees (Sekhavat 2017).

Large companies such as Ubisoft (Roy et al. 2022) and EA (Bergdahl et al. 2021; Sestini et al. 2022) have pioneered several approaches toward intelligent systems within the games development process allowing the assessment of games design such as automated playtesting using deep reinforcement learning agents, as well as the creation of artistic content using neural networks capable of creating state-of-the-art animation controllers that were trained using unsupervised learning techniques applied to motion capture data, proving the real-world interest in the applications of intelligent tools in games development.

Experimental Game Design

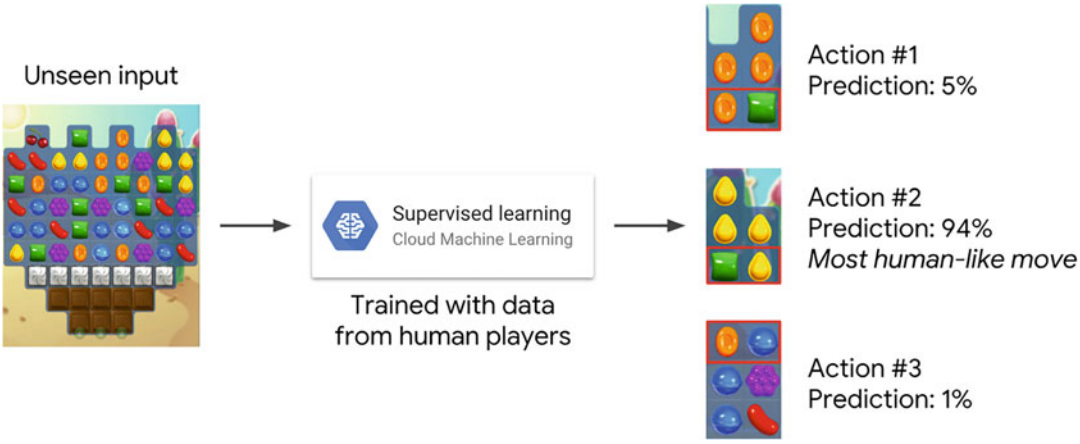
Experimental game design is immensely popular in both early development and later content updates (Waern and Back 2015). Toward the end of the development of a new game or feature, designers with programming skills focus on rapid prototyping to see how the newly created content fits within the existing content and how the implementation achieves the esthetic goals the designers have for the new feature during gameplay. Later within the development cycle of the game, publishers can create experimental versions of the game that players can opt-in to try and explore. This allows designers to test new features on a live player base that is aware that they may experience uncompetitive and less polished experiences, with the benefit being that they are early adopters and will be more prepared when the changes are moved to the live game environment. Through experiments, designers can collect qualitative and quantitative data, which they can use to make informed choices about the trajectory and changes that will be made to the game.

Analytical Game Design Improvements

Analytical design improvement is through the collection and comparison of numbers from game elements directly from the game content, such as weapon parameters or gameplay metrics generated from players playing the game. Using techniques such as cost curve analysis, game designers can accurately measure the fairness and effectiveness of all the content available from the game. Tools and techniques to evaluate the validity of game parameters have evolved over the years. A new addition to the game designer tool belt are machination diagrams, a visual-graph-based language allowing designers to test the design of different game systems (Adams and Dormans 2012). Analytical methods follow a reductive process that allows designers to see the impact of changes immediately within the games' internal systems. Cost curve analysis lists every mechanic and item within a modern game as an item with a benefit and a cost. As the benefit of an item increases, so does the cost Carpenter (2003) value. Designers place the cost increases of an item in line with the benefit of a game, mechanic, or resource, and each item within the world has been referred to as *Jedi Curve* within *Magic The Gathering* Credits (2012). The cost–benefit relationship between each item forms the shape of the curve. During the balancing process, a designer can use it to see where a specific component of the game fits within the system. Small imbalances are allowed, as choosing the most efficient or effective item creates interesting decisions for the players to choose from.

Player Replacements

This section outlines the different approaches to implementing player replacements, which can generate gameplay data for use in automated



Automated Game Design Testing Using Machine Learning, Fig. 1 Crush Saga: Deep Learning AI (Gudmundsson et al. 2018)

playtesting and experimental game design workflows. Player replacements refer to the use of artificial intelligence agents that simulate the player playing the game, making conventional and advanced game testing easier and faster.

New approaches have been proposed to test the design and balance of video games to improve iteration time and precision using automation, and replacements for players have been proposed. Notable examples have been proposed by the AAA games studio *King Entertainment* publisher of the popular "Crush Saga" games. King researched the evaluation of match-3 level design through predicted play test results using machine learning techniques (Gudmundsson et al. (2018) shown in Fig. 1). *Electronic Arts (EAs)* have recently proposed a framework for testing their games using learning agents to accurately reflect the goals of designers and the demographics of the players found in each game (Zhao et al. 2019). Academic organizations and researchers have proposed a broad variety of ideas for how artificial intelligence (AI) can help game designers create games by treating game balance as an optimization problem and using AI to reduce the possible search space, an example of this is by parameter tuning a game "*Shoot 'Em Up"* using active learning techniques (Zook et al. 2019). Another paradigm to accelerate the creation and testing of games that has received attention in academic research is to consider game design or player behavior as a problem domain for reinforcement learning, such as having learning agents design levels (Zhang et al. 2017; Khalifa et al. 2020) or using cutting-edge reinforcement learning algorithms designed to emulate player behavior to generate gameplay data by simulating the game being played (Holmgård et al. 2014; Holmgård et al. 2015). Previous research has shown real progress in testing single-player games. Minimal research has been conducted on the use of machine learning techniques to accelerate the design process of multiplayer games.

Researchers have shown how mathematical representations of simple games can be used to assess the difficulty of the game for different demographics of players (Lee et al. 2021). Research was carried out on target–movement games, which are a popular genre for mobile games that include **Flappy Bird** and **Temple Run**. Evaluating the difficulty is possible by collecting cognitive data from specific player bases and using response times as input into the mathematical representation of the game. Answers to player demographics, response time, and representation of the game allow games to be tuned for different skilled players.

Automated Playtesting

Playtesting a common practice of *Analytical Game Design* is an integral component of user

testing, a fun and engaging game, designed to review design decisions within interactive media, such as games, to measure the esthetic experience of the game compared to the designer's intentions (Fullerton 2008). Playtesting is a lengthy process in terms of both complexity, cost, and time. Several approaches have been presented over the past few years to automate individual sections of this process (Stahlke and Mirza-Babaei 2018). These solutions aim to allow faster, more accurate iterations of design and less waste during development within a professional game development cycle.

Automated playtesting approaches have been pioneered by researchers and game studios to provide automated analytical testing of modern video games. Computer-controlled agents generate data for analysis by designers and stakeholders by playing the game at accelerated speeds and in parallel. Intelligent agents provide greater coverage of available game states, especially in open-ended game worlds, and are implemented using deep neural networks (Bedder 2019). An excellent example of automated playtesting using reinforcement learning was developed by *Prowler.io* to balance two-player games using soft Q-learning (Grau-Moya et al. 2018) that allowed automated playtests to occur in multiplayer environments.

Player Replacements & Personas

Personas have a long history within game design; separating what motivates players into categories allows the game to be assessed for different consumer groups that purchase games for different reasons; each internal driver influences how players interact with the game and can be incorporated into automated game design testing practices. Personas allow the inclusion of different motivations players have when playing games, and personas have been shown to extensively test various single-player games and allow testing in asymmetric multiplayer games with different playable characters (Holmg et al. 2018). Early examples of persona-based player replacements were powered by Monte Carlo tree search and genetic programming techniques. Modern extensions have incorporated different types of player motivation into reinforcement learning algorithms by including an additional reward signal that emulates the type of motivation for each type of player (Ariyurek et al. 2021).

Player Replacements Deep Reinforcement Learning

Work by Google highlights the strength of using machine learning to evaluate game design, and Google researchers developed a prototype game called *Chimera* (Hun Kim and Wu 2021). Google's research focusses on balancing the game by simulating millions of games using a deep reinforcement learning agent. One key issue with this research is the iterative approach and the analysis required before making changes. This tool shows the power of machine learning that allows designers to test an iteration, evaluate the gameplay metrics, and then re-test the game with appropriately designed changes, but does not help designers move the game easily and quickly to a more optimal composition. We believe that this work is a good example of how to automate testing in multiplayer games. The game is not team but features asymmetric gameplay, an example of such a project that was not achieved both at the start of this research.

Approximately, a hundred repetitions are required during the game testing phase of the development cycle to ensure that user interactions produce the expected result (TestDel 2019). A key component of this difficulty is the reliance on human observations to find bugs (Politowski et al. 2021), and excellent research by **Ubisoft** uses computer vision combined with player replacements (Paduraru et al. 2021) to detect issues without human intervention. Intelligent player replacements are able to explore the breadth and depth of the different available game states, and a trained computer vision model performs anomaly detection on the screen output that would be presented to the player. A benefit of this approach is that issues that are flagged to the developers during the testing process are immediately noticeable to the player and allow the priority of the issue; similar techniques that observe the

state of the game world may identify issues that are not noticeable to players. Issues identified using computer vision are highlighted with bounding boxes, allowing the developer tasked with investigating the issue to easily see the anomaly alongside a recording of the required input to recreate the issue, saving hours of debugging and investigation.

Assessing Content with Deep Learning

Approaches to assess generated content that can be achieved using statistical measures have received continued support; work by Lucas and Volz (2019) has shown how computer vision models can be used to generate procedural levels for *Super Mario*. The work uses adversarial neural networks to assess and generate new levels using two separate neural networks trained simultaneously.

> Which can give insight into the generative space of a content generator and its biases within that space. (Liu et al. 2020.

Generated content, such as the level's geometry, can be assessed through artificial play of the generated content. This pursuit has resulted in the generation of different reinforcement learning agents that can simulate the playtesting of PCG (Procedural Content Generation) games. This approach has been shown to evaluate Mario levels generated through an adversarial PCG pipeline (Volz et al. 2018). Automating the testing process can give PCG techniques quick insights into the quality of the generated content. Liapis et al. (2019) approach for generating levels for certain game outcomes using PCG uses AI agents to assess the quality of the generated levels. The work of Baron analyzes different PCG techniques to generate dungeons using analytical methods and allows the adaptation of different algorithms to adjust the content created for different esthetic experiences (Baron 2017).

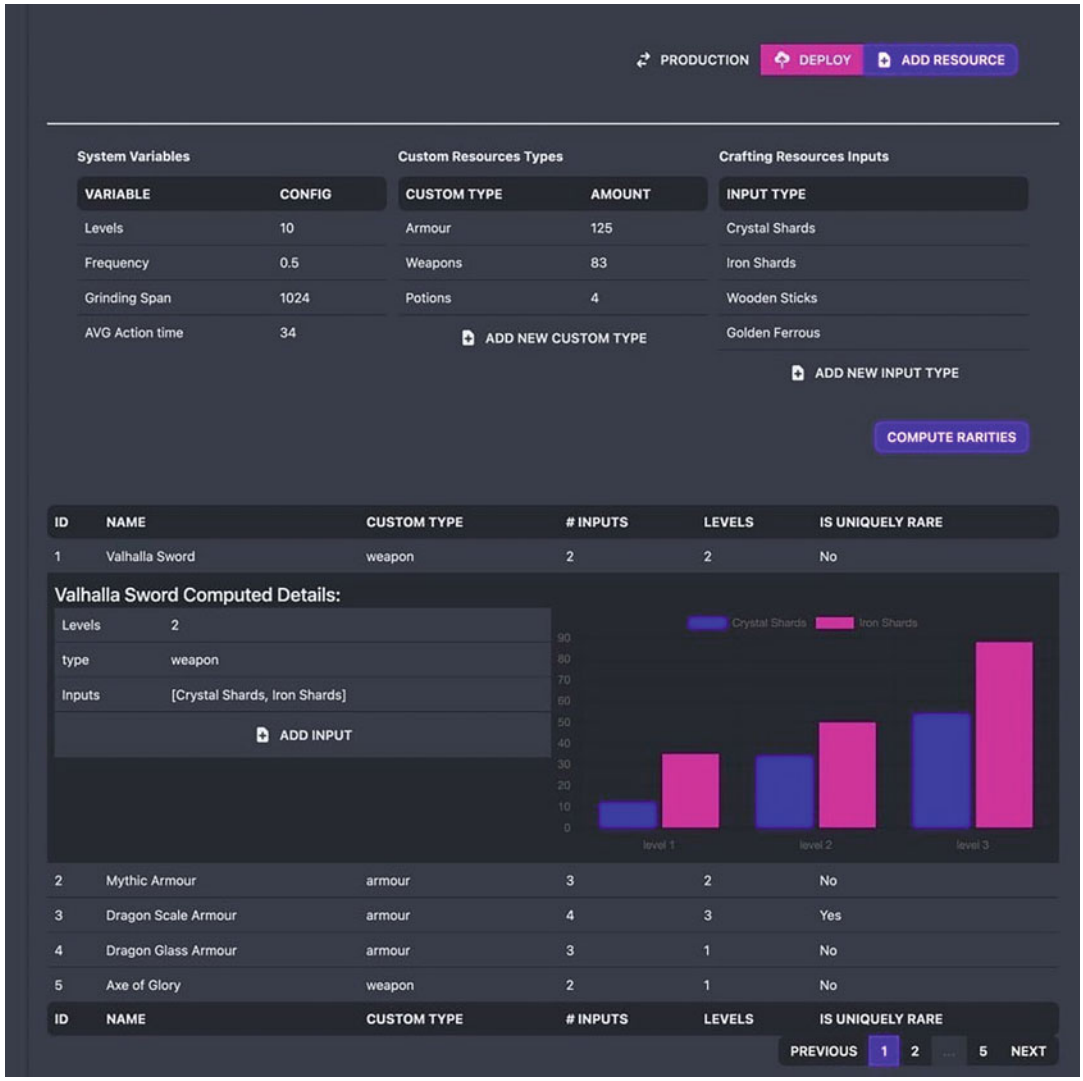
The first type of network composition explored is LSTMs, a popular type of RNN (Hochreiter and Schmidhuber 1997), which are used to generate time sequence data such as text, music, and sound. The second type of network is a generative adversarial network (GAN) that is popular for content generation due to the high levels of fidelity that can be generated from them. This is contributed due to the adversarial nature of the network architecture; GANs (Goodfellow et al. 2014) have two neural networks, one to generate the content and a second to evaluate how accurate the output is; GANs are often taught to students such as counterfeiters and police agents. As the counterfeiter improves creating forgeries, the police network becomes better at discovering fakes or outputs that are not good enough for use case within the game.

The most recent work in this area and the most relevant to this research was conducted by Liapis et al. (2019) and explored using deep learning techniques to evaluate procedural generated content. This work is spread over four key papers. This work uses deep learning to predict the outcome of games from generated data sets. The first paper titled *Using a Surrogate Model of Gameplay for Automated Level Design* refers to this neural network as a "Surrogate Model of Gameplay" (Karavolos et al. 2018), and this terminology is carried throughout the 4 papers. Liapis et al. create a data set to solve several supervised learning problems by simulating games within a first-person shooter by having agents play against each other using behavior trees. Behavior trees define each agent's policy as a branching tree that takes its state from the environment. This decision results in each agent's policy being constant throughout the data generation.

Metanomic: Game Economy Manager

With the rise of NFTs and blockchain games, managing economies have grown in importance as well as intercompatibility. "Metanomic's game economy infrastructure allows developers to build, simulate, and run balanced economies and core gameplay loops in a live, realtime environment" – Theo Priestley, CEO of Metanomic.

The dashboard and analytics tools allow finer-grained controls of the MMO world economies to understand the current supply and interactions players are having with the world's resources. An image of the dashboard can be seen in Fig. 2,



Automated Game Design Testing Using Machine Learning, Fig. 2 Metanomic Dashboard

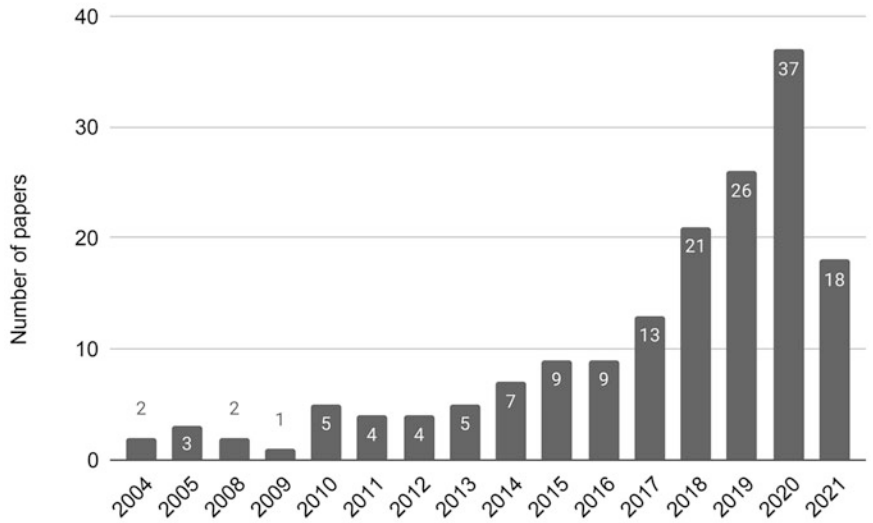
which shows the current inventory of a user and their character's history in the game. Metanomic integrates with machination diagrams and loot tables to provide a comprehensive economy manager for designers; integration with existing game engines is not currently integrated, preventing game mechanics from altering the economic systems, a key source of exploits. Metanomic has acquired *Intoolab* (announced on the 18th of May 2022), an artificial intelligence company that specializes in providing intelligent data analysis on game economies.

Toward Automated Video Game Testing

Exploratory work was carried out to explore the current sentiment toward automated game design techniques within the broader game development industry (Politowski et al. 2022). The research concluded that the desire for automated testing tools and approaches for game development was gaining traction among the survey participants; however, the difficulties of incorporating suitable techniques into existing workflows remain prohibitive toward wider adoption (Politowski et al.

Automated Game Design Testing Using Machine Learning, Table 1 Selected papers for survey, improving game testing with reinforcement learning (Politowski et al. 2022)

Author	Test Obj.	Game tested
Gudmundsson et al. (2018)	Balancing	Match 3
Roohi et al. (2020)	Balancing	Puzzle
Gordillo et al. (2021)	Exploration	3D third person
Holmgård et al. (2014)	Exploration	Doom
Zheng et al. (2019)	Exploration	MMO
Pfau et al. (2017)	Finding bugs	Adventure
Ariyurek et al. (2020)	Finding bugs	3D adventure



Automated Game Design Testing Using Machine Learning, Fig. 3 Histogram of all the 166 papers studying automated game testing over time, improving game testing with reinforcement learning (Politowski et al. 2022)

2022). Politowski et al. (2022) surveyed the sentiment of developers toward a variety of different automated testing approaches from academic research. This was achieved by summarizing the research and asking developers how *desirable, viable, and feasible* the research would be included in their workflow. The final research papers that were included in the questionnaire are included in Table 1. The included research are the filtered results of 166 papers, with 80 papers applying automated solutions to test video games. Each article was separated into semi-automatic and automatic methods; a histogram of the articles over time can be seen in Fig. 3.

This survey has clean insights into perceptions of automated testing in the game's industry despite the small sample size. The technical requirements and processes for each paper were captured in the survey questions, and participants were asked their interest in incorporating or using each technique within their workflow. Some key quotations are given from the survey responses; an example of this is shown below.

> The biggest bang for the buck would be as a build acceptance test on a CI/CD pipeline, making sure the catch obvious blocking bugs. Otherwise, it decreases significantly in usefulness. (Politowski et al. 2022.

This comment is a good assessment of the current consensus on industry sentiment. The biggest obstacle to automated testing is the technical burden that incorporating these features into the game code carries when simply managing a build server brings about significantly more benefits. Other groups have seen this issue around incorporating automated testing into game development by lightening the burden on the developers by packaging the automation as a game engine tool, which has no technical burden on the game source code. An example is *modl.ai's* glitch finder, which plays the game through Unreal Engine's input API and does not add code to the game objects; this framework-styled automation system is wonderful for brute-force tests but falls short of the requirements that would be needed when introducing reinforcement learning player replacements.

Conclusion

A variety of different aspects of game design have been explored by automated testing approaches that range from difficulty prediction (Aponte et al. 2009; Gudmundsson et al. 2018; Lee et al. 2021) that assesses how many lives it would take a player to complete new content and tailor games to different demographics or intended experiences, to higher-level game design that assesses the different options available to players and the viability of the various intended strategies that can be played (Pfau et al. 2020). Automating higher-level game design metrics provides greater value for the production team; however, it comes with greater complexity to implement and compute to assess. Testing of mechanics and systems, such as balancing intransitive relationships, is important; areas of game design that have not been explored focus on both the dynamics, such as the pacing of the game session alongside the frequency and location of key gameplay moments, which are influenced by player cooperation and strategy between different playable characters within multiplayer games. Persistent game worlds have little exploration due to the difficulty of exploring the search space by learning agents, which causes either class imbalance issues during the game balancing process or a lack of data during the assessment process.

Cross-References

- ▶ Area of Interest Management in Massively Multiplayer Online Games
- ▶ Computer Games and Artificial Intelligence
- ▶ Game Player Modeling
- ▶ Machine Learning for Computer Games
- ▶ Overview of Artificial Intelligence

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Automated Image Captioning for the Visually Impaired

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Synonyms

Caption generation; Image captioning; Visual impairment

Definition

Visually impaired	Used in this context to refer to any significant reduction in vision that cannot be compensated for using conventional corrective lenses. Includes total blindness.
Variational Auto-Encoder (VAE)	A machine learning architecture that encodes input data into a representative, lower-dimensional feature space, then decodes it into the desired output format.
Convolutional Neural Network (CNN)	A neural network that uses an image's convolution pyramid to extract its features into a vector representation.
Recurrent Neural Network (RNN)	A neural network that is fed data in sequence and retains information from previous iterations when calculating the output of the current one.

Introduction

Image content in documents can provide important context about the topic discussed within. Though the visually impaired can't access visual content directly, the information images contain can be summarized through captioning. Captions can be conveyed through any conventional method by which the visually impaired access text; these primarily include braille readers and text-to-speech systems. Many documents come pre-captioned however, the captioning tends to be geared towards clarifying image relevance for sighted individuals rather than describing the contents themselves. To remedy this, automated captioning systems have been and are being developed to give the visually impaired some access to this type of content.

Designs of Image Captioning Systems

Most modern image captioning systems rely on a VAE architecture. Many alternatives existed before the popularization of neural networks (Kulkarni et al. 2011) but they have since been either replaced by or enhanced with VAEs.

The first neural image captioning system (Karpathy and Fei-Fei 2015) used a CNN to encode image features and an RNN to generate text captions word by word. While the basic

architecture remains the same, many tweaks to this system have been developed since. A common extension is to include an attention mechanism (Xu et al. 2015) or even replace the RNN and/or the CNN with a Transformer (Liu et al. 2021).

Encoding is the step that has undergone the most drastic changes. These changes primarily take the form of various pre-processing steps. Neural Baby Talk (Lu et al. 2018) first applies an object detection algorithm to the source image before feeding it into the CNN.

Adaptation for the Visually Impaired

While automated image captioning may not have been designed with the visually impaired in mind, its connection is obvious. Several applications have been specifically designed to aid the visually impaired in navigating visual media online and in the real world. These rely on two types of methods which are not mutually exclusive.

Data-Oriented Methods

A key factor for the successful adoption of these models is training on image captioning datasets with labels better suited towards aiding the visually impaired. These captions should contain not just a basic scene description but also include detailed information about the scene and its actors.

One model (Elamri and de Planque 2016) uses a very similar architecture to the basic one described here, with a CNN leading into an LSTM but is trained on the Microsoft COCO Caption dataset (Chen et al. 2015) which uses strong descriptive language in its labels.

Another (Ahsan et al. 2021) uses the Vizwiz dataset which contains images labeled in concert with visually impaired individuals. This training data includes all-important image features that would assist the visually impaired in understanding a scene.

Model-Centric Methods

Better data is insufficient for solving this problem. Models also need to be extended to include more detailed information about individual actors. They also need to be able to handle more complex interactions between them.

The addition of object detection before convolution as in Neural Baby Talk (Lu et al. 2018) allows for more detailed information about individual actors in the scene. This preprocessing step significantly increases performance on more sophisticated image captioning datasets.

Another implementation (Makav and Kılıç 2019) uses a significantly more complicated architecture for the image convolution phase. The architecture in question is VGG16 (Simonyan and Zisserman 2014) which combines image convolution layers with fully connected deep learning layers to allow for higher-level feature extraction.

Combining Approaches

Many applications geared towards the visually impaired lean heavily on a data-centric approach to improvement. While this is an important step, the models being used are not sophisticated enough to capture the high-level language used in the training data. As a result, these projects perform only as well as the associated model would on a normal dataset.

Occasionally performance is even reduced in comparison to those on standardized datasets because the model develops a tendency for memorization due to its inability to learn the complexities present. A common outcome of this is object hallucination (Rohrbach et al. 2018) where objects that often appear together in the same image both appear in the caption, even when one is not in the image being captioned.

Limitations of Current Systems

Image captioning systems used today have a few important limitations that need to be addressed. The most prominent of these is that captions are generally simple and cannot explain interactions in detail. This issue is in large part a matter of limited compute resources and model complexity.

The solution of applying an object detection algorithm before convolution remedies this

somewhat but in turn limits the amount of information carried about the scene as a whole. This type of general information would be important to convey to a visually impaired individual.

Another issue arises in situations where there is text contained within images. While text extraction from images is very nearly a solved problem, no existing solutions take that data into account when generating captions. Without information about the text contained in the scene, the vast majority of an image's meaning could be lost.

These are the primary issues with modern image captioning systems designed for the visually impaired.

Next Steps

Addressing these limitations is by no means a simple task. As one tries to train a model to learn more complex representations, the required model complexity and size goes up drastically. To achieve real progress in these areas it may be necessary to focus on improving model efficiency and downscaling before moving to bigger challenges. In the meantime, it does not hurt to consider potential methods for resolving these issues.

Holistic Scene Understanding

Concerning complete scene understanding outside of object interaction, increasing the CNNs depth, with a VGGNet-based model, for example, may improve overall scene comprehension.

Employing a visual self-attention mechanism within the CNN could provide similar results by emphasizing important connections between image regions (Xu et al. 2015). Taking this a step further and replacing the CNN entirely with a Transformer has been explored as well (Liu et al. 2021).

In-image Text Data

As far as including text recognition in image captioning systems, the obvious solution would be to simply run text detection first and incorporate an embedded vector representation into the feature vector from the image processing network. Unfortunately, this would likely result in the text itself being lost in the process.

An alternative solution would be to use object detection and then explicitly connect the observed text to its corresponding bounding box. This would certainly better capture the contents of the text but may result in poorly phrased captions in unusual circumstances.

Document-Aware Captions

While images often exist independently online, the visually impaired will rarely interact with them. In general, most images would be encountered within another document or web page.

Leveraging this fact could allow the detection of named entities within the text and connecting them to objects detected within the image. This could allow the caption to contain relevant contextual information such as the actual name of a given person or object rather than just the type of object. The corresponding text data could also be used as a basis for generating captions, using a similar methodology to question answering systems trained on large documents.

Conclusion and Discussion

In conclusion, automated image captioning is a complex and interesting field at the intersection of natural language processing and computer vision. The visually impaired would benefit from some access to the information contained within images and captioning is a good starting point to achieve this.

While some work has already been done, there is plenty of room for improvement. Current systems don't capture enough information to be much more useful than baseline models. This is unfortunate, but it means that, as the baseline models improve, so too will their applicability to the situation of the visually impaired.

Cross-References

► Visual Accessibility in Computer Games

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Automated Testing

► Quality Assurance-Artificial Intelligence

Automatic Sound Synthesis

► Procedural Audio in Video Games

B

Basketball Game

► NBA 2K, a Brief History

Battle

► Fortnite: A Brief History

Bayonetta 2, an Analysis

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Synonyms

Hack-and-Slash

Definitions

Action – a genre of games defined by quick gameplay and fighting several enemies in real time.

Hack-and-Slash – a subgenre of action games that challenges the player to fight hordes of enemies that seem weak individually compared to the powerful player character. They typically ask a player to complete a level filled with minor enemies with a more powerful enemy at the end.

Basic Information

- Game Title: Bayonetta 2
- Developer/Publisher: PlatinumGames/Nintendo
- Series: Bayonetta
- Game Engine: Criware
- Platforms: Wii U, Switch
- Release Date: October 24, 2014 on Wii U, February 16, 2014 on the Switch
- Genre(s): Action, Hack "n" slash
- Mode(s): Single player, multiplayer
- ESRB Rating: M

Game Overview and Target Audience

Bayonetta 2 is an action and hack-and-slash game. The target audience for this game are the people who are looking for a fast-paced, thrilling action game.

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https://doi.org/10.1007/978-3-031-23161-2

Gameplay and Mechanics

The gameplay of Bayonetta is a hack-and-slash game that keeps gameplay fresh with a variety of unlockable weapons that can be equipped to Bayonetta's hands and legs giving the player a variety of customization while also changing the way Bayonetta controls and/or interacts with the environment. For example, Bayonetta can equip weapons resembling a chainsaw to her feet and katanas to her legs allowing her to kick with sword attacks and swing with chainsaw attacks, but if a player equips the katanas to her hands she has a larger variety of attack and equipping the chainsaws to her feet allows her to skate with chainsaws on her feet, making her faster and doing chip damage as she whirrs by enemies while also being able to still do kick attacks. Holding the slide button while attacking slices through enemies like a chainsaw would do to a tree.

One of the biggest features of the Bayonetta series is Witch Time. Witch Time is activated when Bayonetta perfectly dodges an attack. It gives the player the upper hand by slowing down time for a couple seconds, allowing for a flurry of attacks to be performed while the enemies are slowed. Witch Time earns Bayonetta more climax toward the Climax Gauge.

When the Climax Gauge is filled, Bayonetta can activate this gauge for an assortment of options. The most destructive option is the Umbran Climax. This allows Bayonetta to perform insanely powerful and flashy attacks, like literally smashing enemies across levels. The gauge can also be used to charge certain weapons and torture attacks.

World, Story, and Characters

Bayonetta 2 takes place on the mountain of Fimbulventr and the depths of Hell. While traveling through and between these realms, the player will encounter enemies from Heaven and Hell.

Bayonetta 2 revolves around a female witch, named Bayonetta, and her journey to save her friend Jeanne's soul from the literal depths of Hell. Bayonetta travels up the mountain of Fimbulventr with an unexpected partner named Loki, a boy who deals with his forgotten past and powers he did not know he could wield. A weapon supplier and infernal bar owner named Rodin helps Bayonetta by creating weapons from the souls of the dead. Bayonetta's somewhat love interest, called Luka, follows Bayonetta trying to solve several mysteries surrounding the events of Loki, Heaven, and Hell. There are only two real antagonists, Loptr and the Masked Lumen, both of which are shrouded in mystery.

Levels

Most of the levels in this game take place in the destroyed town of Noatun, temples, and the depths of Hell.

Interface

The game contains a very solid interface which contains everything a player needs to know while defeating angels and demons. This is Bayonetta's health bar and her climax meter.

On the right side of the screen, the amount of halos/money the player has and their combo points counter is shown.

The bottom right is home to a health bar for larger enemies or bosses.

Public Reception

The public reception of Bayonetta 2 on Switch was received well with 9/10's all down the board from a majority of most major gaming sites. GameSpot reviewer Mark Walton said the game "will be remembered as an absolute classic" and awarded it a perfect 10/10, the seventh game on the site to get a perfect score. This game is praised for being a sequel that feels exactly like the original while also fixing and improving upon the game's formula.

Controversies

Most of the gripes from this game come from it being a Nintendo console exclusive, originally releasing on the Wii U. Although this is true, Nintendo helped revive the franchise as Sega (the previous publisher of Bayonetta 1) wanted to pursue other interests. Although the Wii U version did not sell well due to the console not selling that well, the Nintendo Switch has sold considerably better and the rerelease of Bayonetta 1 and 2, with a third game being teased, has appeased some who had availability complaints.

There is also a strong controversy around the visual representation of Bayonetta as a character in the game. Anita Sarkeesian uses Bayonetta as an example in her "Lingerie is not armor" video on YouTube. However, some other people opine that Bayonetta is a feminist icon.

Similar Games

God of War and Devil May Cry are very similar games (Bayonetta Director Hideki Kamiya worked on the Devil May Cry games), but what

sets Bayonetta apart from these games are the customization options, game mechanics, and the protagonist being a female.

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BCI

▶ Color Detection Using Brain Computer Interface

BCI, Brain–Computer Interface

▶ EEG as an Input for Virtual Reality

Binaural Hearing

▶ User Acoustics with Head-Related Transfer Functions

Binaural Sound

▶ User Acoustics with Head-Related Transfer Functions

Binuaral Headphone Reproduction

▶ Sound Spatialization

Biofeedback

▶ Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being

Biometric and Facial Recognition

▶ Audio and Facial Recognition CAPTCHAs for Visually Impaired Users

Biometric Authentication

▶ Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface

Biosensing in Interactive Art: A User-Centered Taxonomy

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Synonyms

Biosensor technology; Biosignal; Human–computer interaction; Interactive art; Interactive game design; Interactive sound design

Definition

In an interactive artistic context, biosensing studies the detection, measurement, variation, and translation of electrical potentials in the human nervous and motor system as a strategy for controlling parameters in the virtual domain of a digital interactive system.

Introduction

The unprecedented technological advances in terms of computational power, software integration, and miniaturized sensor technologies have fostered new artistic content creation methods in the domains of interactive music, art installations, and digital game design, to name but a few. In this context, biosensing is becoming a pervasive modality of control in interactive systems. In other words, artistic-related practices have been adopting psychophysiological electrical potentials of human subjects, i.e., biosignals, as a strategy to control the creation of interactive content towards adaptive, symbiotic, and immersive experiences.

In this entry, the authors present a user-centered taxonomy of biosensing technology, which aims to guide interactive artists in selecting appropriate biosensors for a particular interactive application design. Particular emphasis is given to the mappings between biosignals' level of control and temporal response and the nature of the system output. In pursuing such a user-centered perspective over biosensing technology, the authors seek to extend existing taxonomies beyond the technical specifications of the sensors, thus, promoting a fluid use of such technology by interactive artists.

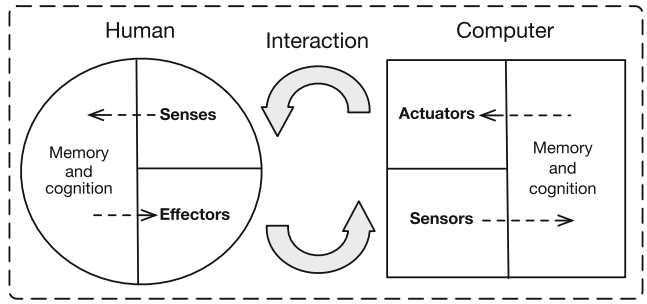
The remainder of this entry is organized as follows. Section "Human–Computer Interaction in Interactive Art" defines concepts such as interactive art, human–computer interaction. Then, in section "Interaction Modalities," is presented artistic-related interaction modalities including biosensing. In section "Towards an User-Centered Taxonomy of Biosensing," the authors review a range of taxonomic perspectives of biosensing technology proposed in related literature and further detail their user-centered taxonomy. Examples of interactive application scenarios of a user-centered taxonomy are presented in section "Application Scenarios of a User-Centered Taxonomy," which discussed typical mappings between biosensor technology and interactive content creation using the proposed taxonomy. Finally, on section "Conclusions," the authors outline the conclusions of their study.

Human–Computer Interaction in Interactive Art

Digital art is increasingly interactive. Some of it is built on interactions that evolved from computer games and device usage. Much of the interaction is intended to engage the audience in some form of interactive experience that is a key element in the aesthetics of the art. The interactive artist is often concerned with how the artwork behaves, how the audience interacts with it and, ultimately, in participant experience and degree of engagement with the art object.

In interactive art, the art object has an internal mechanism that enables it to change or be modified by an environmental factor, or human, which has an active role in influencing the degree of changes (Edmonds et al. 2004). In today's interactive art, where the artist and the audience play integral participant roles, the computer's role has immense potential in defining the degree of interaction, and also managing the real-time result of that interaction. Issues relating to human–computer interaction could be considered as important to interactive art creation as colors are to painting (Candy and Ferguson 2016).

Figure 1 shows the information flow of a human–computer interaction Bongers (2000) as a two-way control and feedback process. When interacting with a computer, humans take action in response to a sensed environment. In turn, computers capture the transformed environment and act accordingly using transducers – *sensor* devices that translate real-world signals into machine-world signals – and *actuators* that translate machine-world signals into real-world signals that can be perceived by humans.



Biosensing in Interactive Art: A User-Centered Taxonomy, Fig. 1 Redraw of Bongers (2000) interaction scheme, which includes two agents: a human and a computer. A feedback loop is created between both agents, which sense the external world using natural and artificial sensors. Both human effectors and computers actuators disturb the environment and act upon it

An example of this interaction loop can be demonstrated with a simple user-control case. When a user presses a computer keyboard key, the system (i) senses the mechanical force applied onto the key, and assigns that action to a specific programmed instruction – a real-world signal is translated into machine-world signal – and, in turn, the system (ii) maps that instruction to a specific symbol and translates a machine-world signal into real-world signal. The result being the visual feedback of the assigned character on the computer screen which can guide the user for future actions.

Thus, to foster human–computer interaction, a system should be equipped with (i) the ability to *sense* the external environment, i.e., a system capable of converting some kind of physical energy, e.g., kinetic or biosignal into electricity and then to codify that input into digital data in order for it to be recorded, analyzed, and manipulated and (ii) the ability to *actuate* on the external environment, i.e., being capable of converting digital data into some form of energy that can be perceived by a human being, e.g., visual/sound or mechanic cues. Sensing and actuating are specifications that allow a system to be controlled, report its current state, and guide the user towards the next possible actions.

In Bongers (2000), both the human and machine's memory and cognition are essential components in building the interaction loop. In an interactive system, ideally the "conversation" between the human and the system should be mutually influenced by the intervention of both humans' and machines' memory and cognition permitting the interaction with information, the changing of the environment, and thereby altering the subsequent information that is received back by the system.

Interaction Modalities

In Bongers (2002), human–computer interaction makes use of what the author refers as interaction modalities – as communication channels between a human and a system – and those interaction modalities involve (i) input modalities which imply senses such as seeing, hearing, smelling, tasting, and touching which are used to explore the surrounding environment and (ii) output modalities, mainly involving the motor system, e.g., handwriting, speaking, or moving things around, that are used use to act on the environment.

Biosensing, as a measurement of the human psychophysiological activity and its use as a strategy for controlling parameters in the domain of a digital interactive system, is an interaction modality of special interest for the present study.

In detail, human psychophysiological activity relates to brain, skeleton, and cardiac muscles, but also skin functions, which all generate electrical potentials. These signals can be measured by electrodes and used to control a digital interactive system. Biosensing captures biosignals (Arslan

et al. 2005; Ortiz-Perez et al. 2011; Ortiz et al. 2015) by detecting, measuring, and translating the electrical potentials in the human nervous and motor system functions, e.g., electromyographic signals, measured on the skin which are related to muscle activity, and electroencephalographic signals, measured on the scalp which is related to brain activity. Recent sensor technology has been developed to detect and measure these functions, notably to support medical care (Stern et al. 2001; Cacioppo et al. 2007; Webster and Eren 2017).

Beyond medical applications, biosensor technology has been attracting the attention of interactive artists who have been increasingly adopting this technology to control parameters of interactive digital systems.

Towards an User-Centered Taxonomy of Biosensing

Existing Taxonomic Perspectives

A wide range of taxonomic perspectives of biosensing technology, rooted in different disciplines and applications, have been proposed in related literature. In Horowitz and Hill (1989), sensor technologies are organized technically according to their electronic circuit design and in (Sinclair 2000) according to the kind of physical energy measured by a sensor, i.e., mechanical, gravitational, electrical, thermal, or magnetic. In Bongers (2000), and referring to the design of interactive musical systems, sensor technologies are categorized based on the ways humans can change the state of the surrounding environment pointing output modalities mainly related to muscle actions, which result in mechanical movement, air flow, or sound production.

In game research, Kivikangas et al. (2011) review the biosense method by presenting a taxonomically review of the application scenarios of biosignal as a way to assess game experience arising from emotional reactions, mainly related to valence and arousal dimensions, and in Leite et al. (2000), Kleinsmith et al. (2003), and Bernhaupt et al. (2007), a taxonomy is presented that takes into account factors such as affective responses by the player to game playing.

Taking into account the use of biofeedback to control game mechanics in Nacke et al. (2011), Pedersen et al. (2010), and Figueiredo and Paiva (2010) Nogueira et al. 2016) formalize biofeedback game mechanics with respect to players' emotional states – modeling player experience for driving interactive content creation.

Table 1 lists biosensor technology commonly adopted in interactive art domain and details the nature of the psychophysiological electrical

Biosensing in Interactive Art: A User-Centered Taxonomy, Table 1 Commonly used sensor technologies in the field of interactive arts and their respective measurable phenomena expressed in hertz (Hz)

Sensor technology	Abbreviations	Measurable phenomena	Frequency (Hz)
Gaze interaction	GAZE	Position, movement, and pupil dilation of gaze with a sensor located on the screen	30
Electromyography	EMG	Activation of facial or body muscle tissues	20–2000
Respiration	RESP	Chest the breathing rate and volume	Measured in extension capacity
Temperature	TEMP	Thermal feedback	Up to 5000
Electrocardiogram	ECG	Electrical activity of the heart	0.05–100
Heart rate variability	HRV	Time difference between two sequential heartbeats	HF (0.15–0.40) LF (0.04–0.15)
Electrooculgram	EOG	Eye motion analysis with a body-worn sensor	DC to 10
Electrodermal activity	EDA	Tonic level of electrical conductivity of skin	0–2.8
Electroencephalogram	EEG	Electrical changes on the scalp	0.05–100

Sensors such as ECG, EEG, EMG, TEMP, and EOG measures in Aller et al. (2000), EDA (da Silva et al. 2014), and HRV (Bakhtiyari et al. 2017). GAZE and RESP sensors have different responses; the latter is measured in extension capacity range, e.g., ranging from 35% to 65%, and the former's accuracy depends on the angular average distance from the actual gaze point

potentials it measures. The sensors were selected based on their common application in interactive arts, availability, low cost, miniaturization, and quick integration with software applications.

A User-Centered Taxonomy of Biosensing

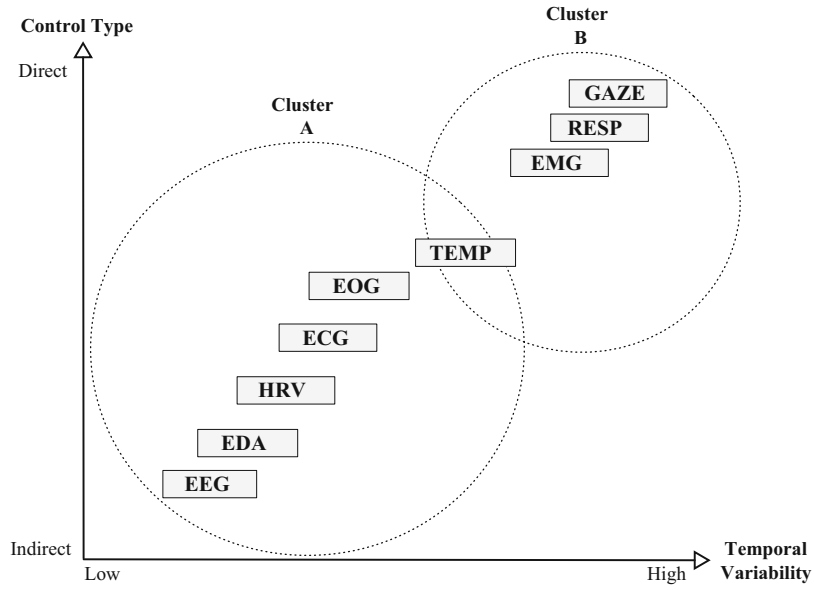
The authors propose a user-centered taxonomy of biosensor technology to assess the broader picture on the use of biosensing technologies as a strategy for controlling parameters in the virtual domain of a digital interactive system. In pursuing such a user-centered perspective over biosensing technology, the aim is to extend existing taxonomies beyond the technical specifications of the sensors, thus, promoting a fluid use of such technology, and its intuitive use, by interactive artists.

In greater detail, the proposed user-centered taxonomy guides the process of selecting the most suitable sensor technology for a specific task based on two dimensions: (i) the degree of control over psycho-physiological human functions, i.e., the ability the subject has to manipulate her own psychophysiological activity and consequently alter the sensor response and (ii) the temporal variability, i.e., the rate of temporal noticeable change in the captured electrical potentials. For example, the author's taxonomy provides an answer to the artist, which aims to use biosignals to control the (long-term) digital game mechanics such as daytime or the weather conditions by pointing to a low temporal variability response sensor with an indirect type of control.

Figure 2 shows the user-centered taxonomy of biosensing technology for interactive art contexts. It includes the biosensors technology listed in Table 1. The two dimensions of the taxonomy, i.e., the temporal variability of the psychophysiological function and the type of control over particular function, are assigned to the horizontal and vertical axes, respectively.

The temporal variability in the horizontal axis reports the degree of temporal variability from low to high. For example, a GAZE sensor has high variability as it measures eye movement, which can naturally be very fast. On the other side of the spectrum, the EEG sensor has a much lower variability as it measures brainwaves can have a slower rate of change. The temporal variability is related to the measurable phenomena expressed in hertz presented in Table 1.

The degree of control over the psychophysiological functions by subjects is denoted in the vertical axis and is expressed in a scale from direct to indirect control. In greater detail, the scale reports the degree of control humans have over their psychopsychological functions and the ability to deliberately alter the response of the captured data. For example, humans have a



Biosensing in Interactive Art: A User-Centered Taxonomy,
Fig. 2 Physiological measures according to a distribution on two axis: on the horizontal axis, the temporal variability response stimuli/sensor, and on the vertical axis, the level of direct control of the electrical potentials generated. The authors denote two clusters, A and B, grouped according to sensor's type of control and response. The measurable phenomena captured by the different sensors is explained in Table 1

direct-explicit control over a muscle impulse, captured by an EMG and a more indirect-implicit control over skin conductivity using an EDA.

In Fig. 2, a diagonal disposition of the biosensors can be identified, showing that the horizontal and vertical axes are intertwined in such a way that the faster the responses obtained from the sensors, the more direct control users have over their measures and evolution. Moreover, from this tendency the authors highlight two overlapping clusters. This overlap is due to the fact that there are sensor technologies which have slow changing responses that can be altered by a sudden change in the environment that they are measuring. An example of this overlap is the TEMP sensor which typically has slow response but the user can induce a more immediate response by blowing air into it.

One remaining dimension is of consideration here: body intrusion. Despite its relevancy in the choice of biosensors for a particular task, the authors believe that the miniaturization of sensor-technology will eventually make it ubiquitous and pervasive in all artistic applications scenarios. Even so, interactive artists must be aware of the pertinence of this dimension when building interactive content.

Application Scenarios of a User-Centered Taxonomy

Based on the two identified clusters in Fig. 2, the authors now discuss typical mappings between biosensor technology and interactive content in two main domains: game design and game audio. The authors believe these same principles can be applied to other forms of interactive biosensing driven art contexts, such as interactive music or performance art.

In game design, biosensors from cluster **A** are typically applied to control implicit, slow-adapting, or background aspects of a game, such as level generation conditions. For example, the slow-changing HRV function can be mapped to evolve long-term game settings such as the weather conditions or to control artificial intelligence aspects of game that are not so noticeable. On the other hand, the slow pace of an EEG measure can be used to define artificial intelligence parameters of nonplayer characters' level of reaction to the player presence. For creating interactive game audio, the sensors from cluster **A** allow the control of higher level musical features such as tempo, i.e., a faster or slower tempo in music expressed in bpm (beats per minute), or the soundtrack general mood, i.e., a more tense or relaxed type of music can be mapped to an HRV sensor.

Biosensors from cluster **B** are better adapted to control explicit interactions or foreground actions. For example, an EMG sensor, which measures fast-changing facial or body muscle tissues, is well-adapted to control player rapid actions, e.g., define the impulse of a character's jump. The fast response and highly controllable RESP sensor can be used to define the number of enemies when the player is trying to accomplish an undercover mission. For interactive game audio cluster **B** is better adapted to control low-level sound features such as the audio level of determined sound effect, e.g., a GAZE sensor can be used to raise the audio level of an observed game object to focus the player's attention or to define the location of a sound event in the scope of the stereo image.

Conclusions

The authors presented a user-centered taxonomy of biosense for interactive arts which aim is to provide artists with a framework to assess the broader picture on its use as a strategy for controlling parameters in a digital interactive system. In pursuing such a user-centered perspective over biosensing technology, the authors sought to extend existing taxonomies beyond the technical specifications of the sensors in order to assess a broader picture of biosensing technologies, thus, promoting a fluid and intuitive use of such technology by interactive artists. By providing use cases examples which discussed typical mappings between biosensor technology and interactive content creation in domains such as game design and game audio, the authors intended to validate their user-centered taxonomy of biosense in interactive art.

Cross-References

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Biosensor Technology

▶ Biosensing in Interactive Art: A User-Centered Taxonomy

Biosignal

▶ Biosensing in Interactive Art: A User-Centered Taxonomy

Bishōjo Game

► Visual Novel

Bit

► Color: Pixels, Bits, and Bytes

Blendshape

► Position-Aware 3D Facial Expression Mapping Using Ray Casting and Blendshape

Blind Bags

► Loot Boxes: Gambling-Like Mechanics in Video Games

Blind Boxes

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Blindness

► Making Virtual Reality (VR) Accessible for People with Disabilities

Block-Based Programming

► Unified Modeling Language (UML) for Sight Loss

Blockchain Games

► NFT Games

Blue Noise Sampling

► Poisson-Disk Sampling: Theory and Applications

Board Game

► Protection Korona: A Game Design on Covid-19

Bodily Presence in Digital Games

► Player-Avatar Link: Interdisciplinary Embodiment Perspectives

Booster Packs

► Loot Boxes: Gambling-Like Mechanics in Video Games

Bounding Box Hierarchy

► Bounding Volume Hierarchies for Rigid Bodies

Bounding Sphere Hierarchy

► Bounding Volume Hierarchies for Rigid Bodies

Bounding Volume Hierarchies for Rigid Bodies

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Synonyms

Bounding box hierarchy; Bounding sphere hierarchy

Definition

A bounding volume is a geometric primitive that encloses one or more objects and leads to cheaper overlapping tests (Ericson 2005). The bounding volumes most frequently used are spheres, boxes, and ellipsoids. The bounding volume hierarchy is a tree structure used to represent the set of geometric objects, which are enclose in bounding volumes. A rigid body is a solid body without deformation or whose deformation is so insignificant that it can be neglected.

Introduction

Bounding volumes and binary space partitioning belong to the acceleration structures used to increase the speed for applications that require to determine intersection between two or more objects. Bounding volume is a technique for object partitioning, which is based on object subdivision and objects level of details, whereas binary space partitioning is a technique for space partitioning, which is based on the space subdivision and space level of details (Luque et al. 2005; Weller 2013). Techniques based on hierarchical bounding volumes are commonly used for collision detection. An object is a triangular mesh, which is bounded by a hierarchy of bounding volumes for collision detection. It is divided hierarchically, usually by a recursive method, and then a bounding volume hierarchy (BVH) is used to represent each part of the object in such a way that the complete object is represented in each level of the BVH. A BVH is a tree structure in which the problem of detecting a collision between two or more objects can be reduced to detect collisions between their BVHs representation. On the one hand, if bounding volumes of two nodes do not overlap, there is no collision for the parts bounded by these bounding volumes. On the other hand, if bounding volumes of two leaf nodes overlap, the corresponding triangles must be tested for intersection. In the next section, it is presented a brief explanation of spheres, axis-aligned bounding boxes (AABB), and oriented bounding boxes (OBB).

Spheres

It encloses an object with the minimal sphere; it is usually called the bounding circumference in a two-dimensional space and bounding sphere in a three-dimensional space (Arcila 2011; Weller 2013; Dinas and Bañón 2015). One advantage of sphere as bounding volumes is its efficiency to calculate the intersections and distance between a pair of sphere. Although spheres are invariant to translation and rotations, they are not good bounding volume for elongated objects. To calculate the bounding sphere, it is found the largest distance between a pair of vertices of the polygon (in two dimensions, see Fig. 1) or polyhedron (in three dimensions).

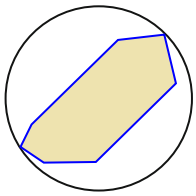
The intersection between spheres is straightforward; it is just enough to calculate the distance between their centers and the sum of their radius, and to compare these quantities. For instance, the pair of spheres depicted in Eqs. 1 and 2 have centers $(x1, y1, z1)$ and $(x2, y2, z2)$ and radius $r1$ and $r2$, respectively.

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = {r_1}^2 \quad (1)$$

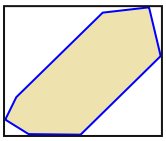
$$(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2 = {r_2}^2 \quad (2)$$

There is not intersection between the circumferences if the condition 3 holds; otherwise they intersect.

Bounding Volume Hierarchies for Rigid Bodies, Fig. 1 Bounding circumference



Bounding Volume Hierarchies for Rigid Bodies, Fig. 2 AABR



$$\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} > r_1 + r_2 \quad (3)$$

Axis-Aligned Bounding Box (AABB)

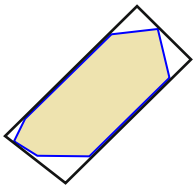
An AABB is a minimal enclosing box that contains the object; it is usually called the axis-aligned bounding rectangle (AABR) in a two-dimensional space and axis-aligned bounding box in a three-dimensional space (Zhigang et al. 2010; Arcila 2011; Weller 2013). The main benefits are that it is simple to find the box, the box is invariant to translations, and the test between a pair of boxes is straightforward; nevertheless, this volume is not invariant to rotation, as a result, changes in the objects direction require updates in the bounding boxes (Fig. 2).

The procedure of testing whether two boxes overlap is simple. Check if one box lies completely on the half-space (not containing the object) of one face of another box, then the two boxes do not overlap. That is, if there exists a separating plane so that two boxes lay on different half-spaces of the plane, they do not overlap.

Orientation Bounding Box (OBB)

It is the minimal box that encloses the object and takes into account the object orientation; it is usually called the oriented bounding rectangle (OBR) and oriented bounding box in a two-dimensional and in a three-dimensional space, respectively (Zhigang et al. 2010; Arcila 2011; Weller 2013). The most significant advantage of this volume is the invariance to translation and rotations; however, the collision test for OBBs (or OBRs) is computationally more expensive than the AABBs (or AABRs) test (Fig. 3).

Bounding Volume Hierarchies for Rigid Bodies, Fig. 3 OBR



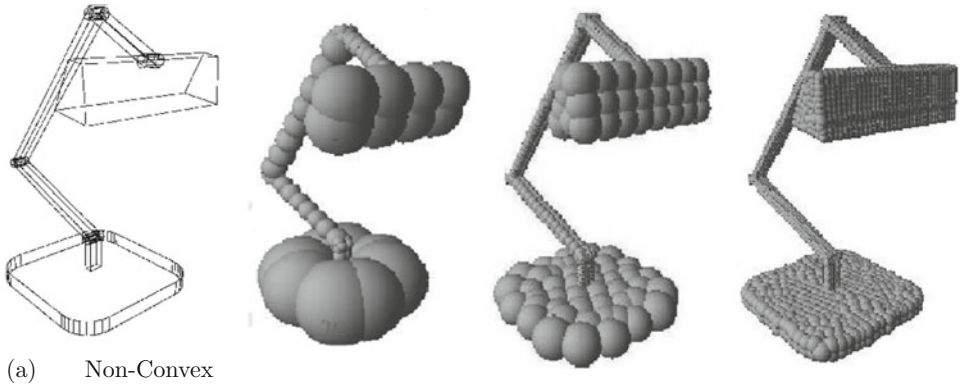
The same procedure used to determine if two boxes overlap can be used to determine the intersection between OBBs.

An Example of Bounding Volumes Hierarchies for Spheres

Figure 4 depicts an example of bounding volumes of a lamp using spheres. Figure 4a shows a nonconvex polyhedron with lamp shape, and it was decomposed into a set of ten parts, which are convex polyhedra. The lamp is compounded by one (1) base, one (1) lamp shade, four (4) pipes or tubes, and four (4) junctions or connectors. In Fig. 4b, there are depicted the three levels of the hierarchy, which has $2^3 = 8$ bounding volumes in each part (80 spheres in total). Figure 4c, d depict the levels 6 and 12 of the hierarchy, respectively; the level 6 has $2^6 = 64$ bounding volumes in each part (640 spheres in total) and the level 12 has $2^{12} = 4.096$ bounding volumes per part (40.960 spheres in total).

Some Bounding Volumes

Following, a short list of common bounding volumes.



Bounding Volume Hierarchies for Rigid Bodies, Fig. 4 Representation of an object Lamp by spheres. (Dinas et al. 2009)

- *Ellipsoid*: Ellipsoids are tighter fitting than spheres for elongated objects (Rubino et al. 2015).
- *Cylinder*: It uses the radius of bounding circumference of the shape and a swept line (Chan and Tan 2004).
- *K-Discrete Orientation Polytopes (K-DOPs) or Fixed-Direction Hull (FDH)*: A DOP is a generalized AABB. It is constructed by taking a number k of appropriately oriented planes at infinity and bringing them closer to the object until they collide (Weller 2013; Dinas and Bañón 2015).
- *Oriented Discrete Orientation Polytopes (Or-DOPs)*: An Or-DOP is similar to a K-DOP, but it is a generalization of an OBB rather than an AABB (Suaib et al. 2013).
- *Swept Sphere Volume*: The representation is straightforward: a radius and a swept volume. The most important swept volumes are point swept spheres (PSS), line swept spheres (LSS), and rectangle swept spheres (RSS). The advantages of these volumes correspond to the sphere advantages (Tang et al. 2014).
- *Cloud of Points and Convex Hull (CPCH)*: It constructs a convex hull for a cloud of points; it is the smallest convex volume containing the object and, hence, a hull is a tight bounding volume (Figueiredo et al. 2010). Research on clouds of points includes mostly surface reconstruction; they are important for animated three-dimensional graphics.

The combination of two or more BVHs was proposed by (Arcila 2011) as a double BVH. The outer (minimal) bounding volume has been widely used; it determines the collision and accelerates the process in broad-phase, whereas the inner (maximal) bounding volume accelerates the collision acceptance process. Additionally, a combination of AABB and ellipsoids for three-dimensional for a sequence of images was recently proposed by Rubino et al. (2015), they worked on objects reconstruction from a sequence of images in open and close scenarios.

Bounding Volumes Requirements

Several literature about the bounding volumes includes the importance, minimal requirements, construction cost, test cost, evaluation tests, techniques, applications, among others (Zhigang et al. 2010). Because of their importance, several authors have reported their impact and cost of computing, and have implemented strategies to decrease the cost (Yoon and Manocha 2006), whereas other authors have reported works on requirements for optimal bounding volumes (Weller 2013):

- *Tight fitting to approximated objects*: Tighter fitting bounding volumes are computationally expensive; it is hard to calculate a unique bounding volume that adjusts different objects. Hierarchies are one solution to approximate the object (Bradshaw 2002).
- *Efficient creation*: The complexity of the bounding volume is mainly the complexity of its creation; however, more complex volumes should be tighter fitting (Lauterbach et al. 2009).
- *Efficient updating*: If a bounding volume is invariant to rotation and translation, it does not require to be updated; however, not always they are invariant to both geometrical transformations (Spillmann et al. 2007).
- *Efficient overlap tests*: Low computational costs are associated with simpler bounding volumes (as spheres and boxes); however, they are not as tighter fitting as others (Zhigang et al. 2010).
- *Low memory usage*: The simpler bounding volumes use lower memory and have low computational cost; nevertheless, they are not as tighter fitting as others (Yoon and Manocha 2006; Weller 2013).
- *Suitable for hierarchy construction*: A bounding volume tree helps to decrease the number of overlapping tests, and they can be used to approximate the objects shape (Spillmann et al. 2007).

All requirements are essential; however, there is not a bounding volume that fulfills them completely; the selection depends on the application. Nevertheless, efficiency in bounding volumes is equally important to the following requirements of the hierarchy (Bradshaw 2002):

- *Volume Approximation*: Children nodes represent tighter fit of the object than its parent.
- *Covered Area*: Children nodes must cover the same parts of the object covered by their parent.
- *Automatic Creation*: Hierarchy construction does not use human interaction.
- *High Degree of Accuracy*: Bounding volumes should fit the original model as tightly as possible.

Bounding Volumes Performance

Performance of Bounding Volumes can be evaluated using Eq. 4 (Bradshaw 2002; Weller 2013; Dinas and Bañón 2015).

$$T = N_u C_u + N_v C_v, \tag{4}$$

where T is the total cost function for detecting interference between a pair of objects represented by a bounding volume. N_u is the number of bounding volumes updates during the traversal of the hierarchies, and C_u is the average cost of updating a bounding volume due to the motion. N_v is the number of overlapping tests performed over the bounding volumes, and C_v is the average cost of performing an overlapping test between a pair of bounding volumes.

However, Eq. 4 was extended to Eq. 5 in order to separate bounding volumes and primitives (Weller 2013).

$$T = N_u C_u + N_v C_v + N_p C_p, \tag{5}$$

where N_p is the number of overlapping tests performed over primitives, and C_p is the average cost of performing an overlapping test between primitives. (Suaib et al. 2013) included C_o in Eq. 6. C_o is used to include any additional time caused by transformation updates or coordinates updates for the objects. Similarly, Ericson (2005) define C_o as a one-time processing.

$$T = N_u C_u + N_v C_v + N_p C_p + C_o \tag{6}$$

For instance, due to spheres and OBBs are invariant to rotation, they eliminate the values N_u and C_u from Eqs. 4 and 5 but the value N_v increases. In contrast, the reduction of overlapping test over the bounding volumes (N_v) increases the number of overlapping test over primitives (N_p).

Cross-References

▶ Collision Detection

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Braille

▶ Unified Modeling Language (UML) for Sight Loss

Brain Computer Interface

▶ Color Detection Using Brain Computer Interface

Brain Control Interface

▶ Gaming Control Using BCI

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface

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Synonyms

Biometric authentication; Brain-computer interface; EEG signal

Definitions

Human biometric techniques are presented as another type of security authentication to cover

the problems of password authentication. Brainwave is another human biometric, which recently is one of the popular subjects for scientists and researchers. Brain-computer interface (BCI) is a method of communication based on neural activity's communication created by the brain.

Introduction

In the past, people used to have a suitcase to keep their important documents like keys, money, bank account booklets, letters, photos, etc. which they could lock the suitcase to keep them secure. Today, people can keep all of that information in their personal computers, mobile devices, social networks, and the cloud storages, which in this case, information security and data protection play a crucial role in them. Security and accurate authentication methods have become a top priority within information security, which is necessary as it allows companies and people to keep their systems and devices protected by authorizing only authenticated users to use important resources (Margaret).

There are several methods of authentication (Darril) such as something you know (password or PIN), something you have (smart card, common access card (CAC) (DeBow and Syed 2016), personal identity verification (PIV) (Kittler et al. 2002), or RSA token (Vangie)), and something you are (using biometrics). Password or PIN authentication and different kinds of smart cards and tokens are easy to implement but because of this ease can be very easily stolen or lost. Biometrics is a new technological alternative to solve this problem (Jain et al. 1999). These typical biometric authentication technologies have some disadvantages (Erden). Therefore, a new biometric method needs to be produced to reduce the number of disadvantages that are within current systems. Brain signal is a human's characteristic, which does not have the problem of visibility to copy it, and it does not have the disadvantages of other biometric systems if the authors could employ it as a biometric authentication. Human brain signals are one of the characteristics that, nowadays, scientist and researchers are working on using brain-computer interface (BCI). BCIs are systems that provide communications between human beings and machines.

In the past, people always liked to read each other's mind or it was a wish for them to control their environments or replace objects with their brainpower. Today technology made those dreams happen. For instance, transfusing signals straight to someone else's brain to allow them to experience new sensory inputs like sight, hearing or feel. One of the potential outcomes of the future could be the manipulation of computers and associated devices with the simple transferring of a thought. Considering this potential BCI could be a very significant breakthrough within technology. BCIs are becoming increasingly popular in medical and non-medical areas as a way of communication to be conducted between humans and machines. Nowadays brain signal authentication using BCI devices is one of the popular subjects for researchers.

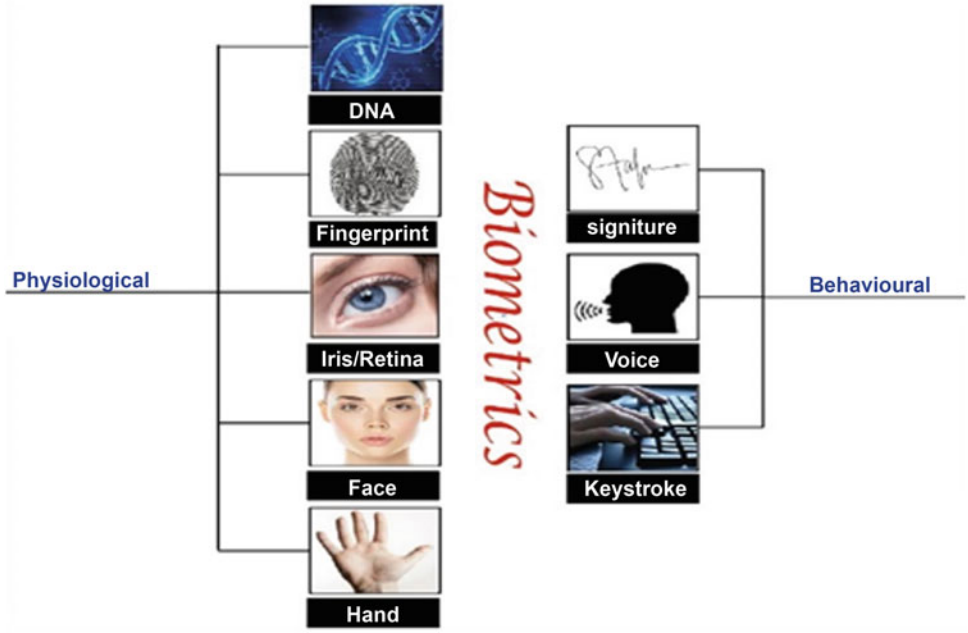
This article is a survey about biometric authentication techniques and using brain signals via BCI technologies as a new biometric authentication technique of a human body, which could be the most secure technology in the future.

Overview on EEG Signals

A review about biometric authentication in a couple of research papers and a literature review about BCI and brain signal authentication from the previous experiences of the other researchers, which are categorized to different subjects and goals, are as follows:

Biometrics

The word biometrics is a combination of two Greek words, "bios" (life) and "metrikos" (measure). This technology is mostly used for access control and identification or for identifying people who are under investigation (Faundez-Zanuy 2006). There are two different concepts in biometrics, which the authors should concentrate on, behavioral/physical biometrics and authentication/identification. Behavioral biometrics concentrates on analyzing the non-physiological or non-biological structures of any human. It studies the unique psychological characteristics of humans like signature, voice, gait, and



Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Fig. 1 Physiological and behavioral biometric types

keystrokes. Physical biometrics is doing the opposite, which is focusing on analyzing the physiological and biological structures of the human (Agrafioti et al. 2009). As you can see in Fig. 1, there are a couple of different behavioral and physiological human biometric types.

Biometric Authentication Types, Advantages, and Disadvantages

A biometric technique can work in two modes, authentication and identification, which are the heart of the biometric science (Prasanna et al. 2012). Biometric authentication is one of the most popular ways to provide personal identification because these characteristics of a human are specific and unique. Most of these specific features are so hard to duplicate and accurately produce (Kodituwakku 2015). In terms of information security, physiological biometric traits appear more practical. The most popular physiological biometric techniques are as follows:

Face Recognition

In comparison with the different biometric identification techniques, "face recognition is one of the most flexible, working even when the subject is unaware of being scanned" (Jafri and Arabnia 2009). It works by methodically analyzing particular characteristics that are common to human's face such as the size of the nose, the space between the eyes, position of cheekbones, jawline, and so forth (Margaret, Facial recognition). Table 1 shows some specific advantages and disadvantages of this biometric technique (Masupha et al. 2015).

Fingerprint Identification

Fingerprints are the most famous biometric which remain constant throughout life. It is more than 100 years in worldwide fingerprint comparison that no two same fingerprints were found. "Fingerprint identification involves comparing the pattern of ridges and furrows on the fingertips, as well as the minutiae points (ridge characteristics that occur when a ridge splits into two, or ends) of a specimen print with a database of prints on file" (Kute and Kumar 2014). Table 2 shows some specific advantages and disadvantages of this biometric technique (Tarun).

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 1 Face recognition biometric advantages and disadvantages

Face recognition	
Advantages	Disadvantages
Prevent card counters, etc. from entering casinos	Isn't accurate at all times
	Hindered by masks, glasses, long hair, etc.
Identify criminals, terrorists, etc.	Pictures must be taken when the users have a neutral face
Find missing people	"Considered an invasion of privacy to be watched"
Prevents elector frauds	
Targets shoppers	Easy to abuse

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 2 Fingerprint biometric advantages and disadvantages

Fingerprint identification	
Advantages	Disadvantages
It is one of the most developed biometrics	It needs more computer memory to store scanned data
Very high accuracy	
Easy to use	
Is the most economical biometric PC user authentication technique	Using the fingerprint scanner does not take into consideration when a person physically changes
It is standardized	
Small storage space required for the biometric template, reducing the size of the database memory required	It can make mistakes with the dryness or dirtiness of the finger's skin, as well as with the age (is not appropriate with children, because the size of their fingerprint changes quickly)

Retina Scan

In the backside of the eyeball, there is a layer of cells, which is the retina. This part of the eye converts light into nerve signals. To replicate a retina, there is no known way discovered. The pattern of the blood vessels at the back of the eye is unique. It stays the same for the whole lifetime (Choraś 2012). Table 3 shows some specific advantages and disadvantages of this biometric technique (Jatin).

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 3 Retina biometric advantages and disadvantages

Retina scan	
Advantages	Disadvantages
Like fingerprints, retina traits remain stable throughout life	Retina scan enrolments take longer than both iris scan and fingerprinting
Its resistance to false matching or false positives, regarding to pupil movements	Users claim discomfort with eye-related technology in general and the fact that retina scan technology has limited uses
The eye from a dead person would deteriorate too fast to be useful, so no extra precautions have to be taken with retinal scans to be sure the user is a living human being	Users commonly fear that the device itself or the light inside the device can harm their eyes in some way
	Users claim discomfort with the fact that they must position their eye very close to the device
The retina is located deep within one's eyes and is highly unlikely to be altered by any environmental or temporal condition	Many also feel that these retina scans can be linked to eye disease

Iris Scan

Iris is another part of the eyes, which has complex patterns that are stable, unique, and, in compare to the retina, can be observable from a long distance. The pattern-recognition method in Iris Scan process is using video images from a person's iris. In iris identification, the probability of error is the lowest of all biometrics. (Shekar and Bhat 2015). Table 4 shows some specific advantages and disadvantages of this biometric technique (Biometrictoday).

Current Biometric Technique Advantages and Disadvantages

Biometrics have too many different techniques and methods. After investigating some of the physiological biometric methods and the specific advantages and disadvantages of them, the authors are going to peruse the current biometric technique's advantages and disadvantages. Table 5 shows advantages and disadvantages of recent biometric methods (Le and Jain 2009).

Brainwaves as a New Biometric Authentication

The potential for using brainwaves as human biometric identification has risen to the surface once

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 4 Iris biometric advantages and disadvantages

Iris scan	
Advantages	Disadvantages
Scalability: This technology is highly scalable and can be used in both large- and small-scale programs	**Distance:** Iris is small and cannot be located from a few meters distance
Accuracy: Iris recognition is one of the best biometric modalities in terms of accuracy	**Expensive:** Iris scanners are relatively higher in cost compared to other biometric modalities
Stable: Iris patterns remain stable throughout an individual's life. It is protected by the body's own mechanism	**Infrared light:** The constant use of this system may cause harm to the iris because it is constantly being scanned with infrared light
Noninvasive: Iris recognition can be done with simple video technology. No use of laser technology is necessary to scan the iris making it a noninvasive technology altogether	**Movement:** A person has to be steady in front of the device to be enrolled by iris scanners. It means this device cannot be used like face recognition devices to scan anybody, regardless of their movements
Easy to use: Iris recognition system is plug and play compared to other modalities of biometric recognition. A person needs to stand still in front of the camera, and the job is done instantly. It is a comfortable process for everyone	**Obscure:** Eyelashes, lenses, and reflections, which create a problem, more often than not, obscure it
Fast: With iris recognition system, a person can complete the process within just a few seconds	**Reflection:** In some cases, it is hard to perform an iris scan due to the presence of reflections. It could happen in case of eyelashes, lenses, and anything in general that would cause a reflection
Traceable: The encoding and decision making of iris pattern is traceable. It takes only 30 milliseconds for the image analysis and the subsequent encoding	**Memory space:** A lot of memory is required for the data to be stored and later accessed
	Transformation: Iris may deform nonelastically as the pupil may change its size due to medical or other conditions

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 5 Biometric methods' advantages and disadvantages

Biometric advantages and disadvantages	
Advantages	Disadvantages
Convenient: The credentials are with human forever, so it does not require you to memorize or note down anything	**Physical traits are not changeable:** Users can reset a password, but they never can change their fingerprints or retina; these are fixed
Security: Biometric technology brings different types of solutions, which are nearly impossible to hack unlike passwords	**Unhygienic:** In contact-based biometric techniques, a biometric device is used a lot of times by enormous amount of people. Everyone is actually sharing his or her germs with each other via the device
Scalability: Unlike other solutions, biometrics are highly scalable solutions for all types of projects. It is possible for any kinds of projects because of the scalability of its solutions	**Error rate:** Usually, biometric devices make two types of errors, false acceptance rate (FAR) and false rejection rate (FRR) (Wayman et al. 2005). When the device accepts an unauthorized person, it is known as FAR, and when it rejects an authorized person, it is known as FRR
Accuracy: Biometric works with individual's physical traits such as fingerprints, face, and retina among others that will always serve you accurately anywhere, anytime	**Delay:** Some biometric devices take more than the accepted time and a long queue of workers form waiting to be enrolled in large companies
Flexibility: People have their own security credentials with you, so you do not need to bother memorizing awkward alphabets, numbers, and symbols required for creating a complex password	**Environment and usage matters:** Environment and usage can affect the overall measurements taken
Save money: With a little money, any company can track their employees and reduce the extra costs they are paying for years	**Physical disability:** Some people are not fortunate enough to be able to participate in the enrolment process. They might have lost or

(continued)

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 5 (continued)

Biometric advantages and disadvantages	
Advantages	Disadvantages
	damaged body parts such as fingers or eyes
Save time: Biometric solutions are highly time conserving	
Trustable: Reports claim that the young generations trust biometric solutions more than other solutions	

again, an idea presented as a way to distinguish humans with thoughts. Before becoming a method of security, it could be the measuring standard for biometric identification in the near future, but it needs more time and work on it. Brain signal can be one of the most practical biometric authentication methods (Fig. 2). It is obviously a possible technique of identification, and in terms of security, it could have a big role to play in the feature.

Neural Oscillations (Brainwaves)

Neural oscillations or brainwaves are an essential mechanism to enable the synchronization of neural activity inside and around brain areas and help the accurate temporal organization of neural processes underlying memory, cognition, behavior, and perception (Neustadter et al. 2016). "The interaction between neurons can give rise to oscillations at a different frequency than the firing frequency of individual neurons" (Roux and Uhlhaas 2014).

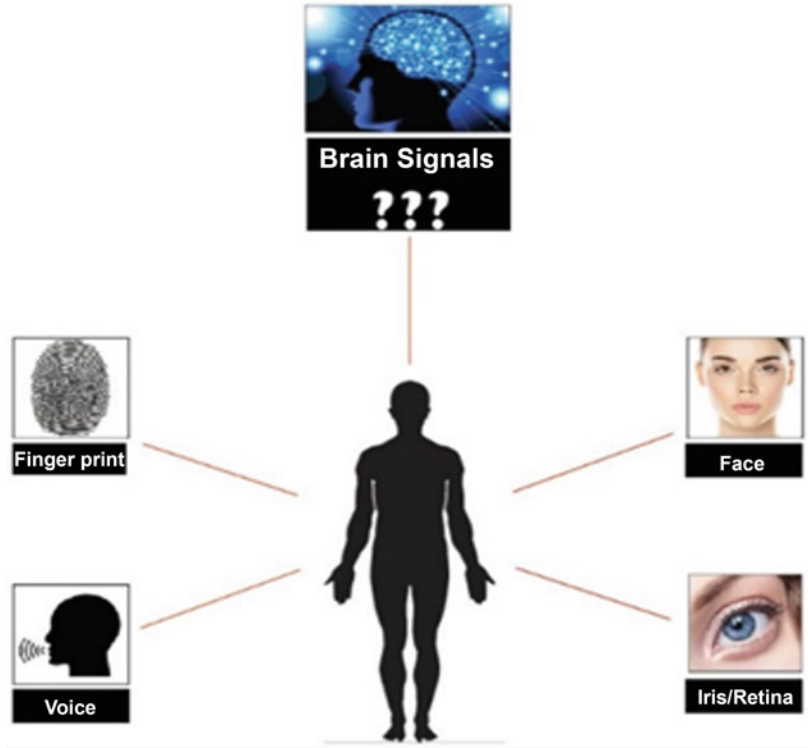
Electroencephalography (EEG)

Hans Berger was a German psychiatrist who observed the first human neural oscillations as early as 1924. He invented electroencephalography (EEG) for the recording of "brainwaves" by measuring electrical activity in the patient's brains in the hospital which had a skull damage (Millet 2002). EEG is one of the techniques for brain imaging. Table 6 shows the different brain imaging techniques (Imotion EEG packet guide).

Electroencephalography (encephalon = brain) or EEG is an electrophysiological observing technique to capture electrical activity generated by the brain from electrodes placed on the scalp surface (Niedermeyer and da Silva, 2005). "EEG refers to the recording of the brain's spontaneous electrical activity over a period, as recorded from multiple electrodes placed on the scalp" (Niedermeyer and da Silva 2005). Many of the brain's emotion recognition techniques have been implemented and proposed for the last few years which most of them involved the extraction of EEG signals (Abuhashish et al. 2015). In comparison to other imaging methods, EEG has some benefits. It is an excellent tool for studying the processes of neurocognitive underlying person behavior because of some reasons such as the following: (1) EEG has very high time resolution and captures cognitive processes in the time frame in which cognition occurs. (2) EEG directly measures neural activity. (3) EEG is inexpensive, lightweight, and portable. (4) EEG monitors cognitive-affective processing in the absence of behavioral responses (Catarino et al. 2011). In terms of frequency, there are five types of brainwave (gamma, beta, alpha, theta, delta), and "each frequency is measured in cycles per second (Hz) and has its own set of characteristics representing a specific level of brain activity and a unique state of consciousness" (Korde and Paikrao 2018). This is represented in Table 7. According to the types of brainwaves, four different kinds of mental activities such as movement, emotions, talking, and motor imagery have been measured by investigators (Abuhashish et al. 2014).

Brain-Computer Interface (BCI)

"Brain-computer interface is a method of communication based on neural activity generated by the brain and is independent of its normal output pathways of peripheral nerves and muscles" (Vallabhaneni et al. 2005). BCIs are developed by the research community with some applications in mind to the generation of new assistive devices (Rao and Scherer 2010). Brain-computer interface technology is a powerful communication tool for both users and systems. "The BCI has the capacity to access brain activities and impart relevant



Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Fig. 2 Brain signals beside the most practical biometric authentication techniques

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 6 The methodology of brain imaging techniques and the ways that they work

Brain imaging techniques		
Methodology	What is imaged?	How?
Electroencephalography (EEG)	Changes in electrical brain current	Electrodes placed on scalp measure electrical brainwaves
Positron emission tomography (PET)	Emissions from radioactive chemicals in the blood	Radioactive isotopes injected into the blood are detected like X-ray
Computed (axial) tomography scan (CT or CAT)	X-ray images of the brain	Multiple images (tomograms) are taken by rotating X-ray tubes. Doesn't image function
Functional magnetic resonance imaging (fMRI)	Blood flow; oxyhemoglobin-to-deoxyhemoglobin ratio	Relies on the magnetic properties of blood. Shows brain function spatially and temporally
Magnetoencephalography (MEG)	Changes in electrical brain current	Similar to EEG but magnetic brainwaves are measured instead of electrical brainwaves

information on the emotional status of the user" (AbuHashish 2015). There is no need for any external devices or muscle involvement to issue instructions and complete the communication (Bi et al. 2013). Normal individuals have been targeted in most recent studies by exploring the use of BCIs as an input device and exploring the generation of hands-free applications (van Erp et al. 2012).

BCI Types

The BCI can be separated into invasive, partially invasive, and noninvasive types (Abhang et al. 2016). In invasive BCI, recording the signals occurs when electrodes enter the brain tissue. This is a permanent basis method, which buries electrodes within the brain. Partially invasive BCI is a process in which electrodes are placed inside

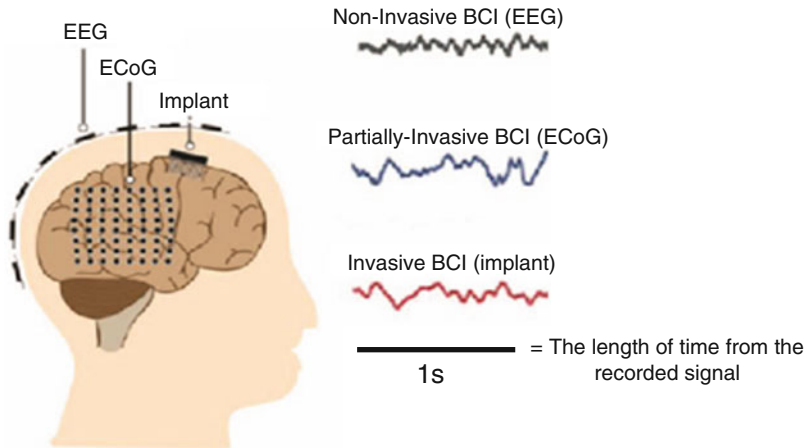
of the skull but rest outside the brain rather than within the gray matter above the brain's surface. A good example for partially invasive BCI is electrocorticography (ECoG). ECoG is a type of monitoring that uses electrodes placed directly on the bare surface of the brain to record brainwaves from the cerebral cortex (Palmini 2006). In non-invasive type of BCI, no surgery is needed. Instead, the sensors or electrodes are placed over the head (via a hat, belt, patch, or a headset) to measure electroencephalography (EEG), which reads the rhythm of brain activities (Mayoclinicstaff Electromyography (EMG)). There are many brain devices that are used to capture brain activities. These devices are brain controllers, which are very common technologies in the BCI area that can read the electrical brain functions (Abuhashish et al. 2015b). The following image (Fig. 3) shows the different layers of the brain and where the signal is taken from by three different methods such as EEG, ECoG, and implant.

BCI System Process

A BCI is a system that can distinguish a definite set of forms in brain signals following five sequential stages (Fig. 4): signal acquisition, preprocessing or signal enhancement, feature extraction, classification, and the application interface (Khalid et al. 2009). You can see in Fig. 4 that the first part of BCI process starts with acquiring the signals from the brain and goes to the next section,

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 7 Types of brainwaves and their frequency rates and mental state situation

Wave	Frequency	Mental state
Gamma	Above 40 Hz	Thinking, integrated thought
Beta	13–40 Hz	Alertness, focused, integrated, thinking, agitation, aware of self and surroundings
Alpha	8–12 Hz	Relaxed, non-agitated, conscious state of mind
Theta	4–7 Hz	Intuitive, creative, recall, fantasy, dreamlike, drowsy, and knowing
Delta	0.1– 4 Hz	Deep, dreamless sleep, trance, and unconscious

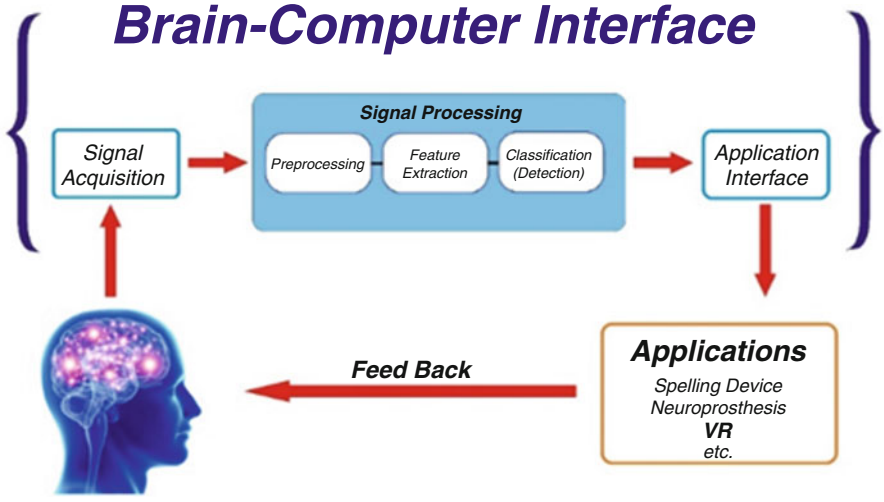


Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Fig. 3 The way that BCI captures the signals from the human brain (Mayoclinicstaff Electromyography (EMG))

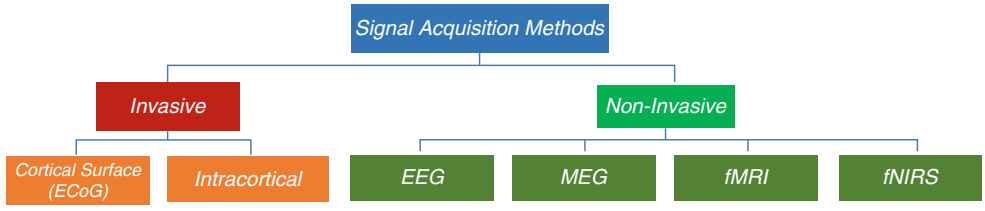
which has three subsections for signal processing to make the signal ready to use in different applications and for different purposes.

Signal acquisition is a considerable challenge in the field of BCI. Some methods focus on EEG signals; however, other methods exist that can capture neurological activity. End use is a factor that is intended by the designer which filters out which method you should use for capturing specific signals (Major and Conrad 2014). Different methods for signal acquisition have been studied. There are two general classes of brain acquisition methods, which are invasive and non-invasive (Fig. 5). Each method is using different types of BCI devices.

After signal acquisition part, signals are going to be preprocessed. Signal preprocessing is also called signal enhancement (Norani et al. 2010). In general, the acquired brain signals are unclear by noise and artifacts. The artifacts are eye blinks, eye movements, and heartbeat. In addition to these, muscular movements and power line intrusions are also mixed with brain signals (Bin et al. 2009). A couple of different methods are used for artifact removal which "the most frequently used methods are Common Average Referencing (CAR), Surface Laplacian (SL), Common Spatial Patterns (CSP), Independent Component Analysis (ICA), Principal Component Analysis (PCA) and Adaptive Filtering" (Lee et al. 2010). Overall, these techniques have specific purposes that could match each objective of experiments conducted (Mallick & Kapgate, 2015).



Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Fig. 4 Brain-computer interface process



Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Fig. 5 Brain signal acquisition's methods

After preprocessing and filtering, the EEG signals will pass through feature extraction process and select particular features by some feature selection methods. Some researcher used a hybrid BSS-SVM system to extract the movement-related features from the EEGs (Peterson et al. 2005). In most existing BCI, this identification relies on a classification algorithm. Using classification algorithms is the most popular tactic for this purpose. These procedures are used to identify "patterns" of brain activity (McFarland et al. 2006).

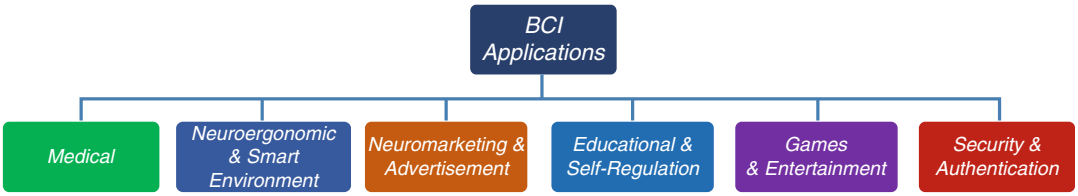
Classification algorithms divided into five different categories: linear classifiers, neural networks, nonlinear Bayesian classifiers, nearest neighbor classifier, and combinations of classifiers (Lotte et al. 2007). BCI has many applications, especially for disabled persons. It reads the signals generated by the brain and translates them into activities and commands that can control the computers (Lotte 2006). Figure 6 shows the different types of BCI applications.

BCI Security Authentication Using EEG Signals

As the authors mentioned before, a couple of different ways are there which are designed for acquiring the brain activities noninvasively, including magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), near-infrared spectroscopy (NIRS), and electroencephalography (EEG). In comparison to other methods, EEG is a noninvasive method, which is not very expensive and allows recording the signals passively. EEG-based user authentication systems are currently popular in BCI security and authentication applications. Recently, scientists and researchers have been doing many attempts to observing the pattern uniqueness of the brain signal. Several different methods have been used to analyze EEG signals. In regard to the recent progression of EEG signal acquisition devices, the capability of providing better results is going higher, and these processes are getting simpler. The authors are going to review a couple of different tactics of EEG capturing methods to acquire better accuracy and check the applicability of using signal authentication purposes. There are four different studies in this research area that were more successful and reported better accuracy in their experiences (Jayarathne et al. 2017) which are linear discriminant analysis (LDA), cosine similarity → LDA, power spectral density (PSD) and spectral coherence (COH) → Mahalanobis distance and match-score fusion, and event-related potentials (ERP). These studies used different tasks, extracted features, and classifiers for doing their experiments to get higher accuracy rates of brainwaves to use them for authentication purposes. Besides the studies mentioned above, Table 8 summarizes some other studies with achieved accuracy and other characteristics. Generally, accuracy of each system depends highly on these aspects.

Discussion

Recent biometric user authentication techniques have some problems and limitations. To cover the recent biometric limitations, we need a new biometric brainwave-based authentication, which is another technique in the extensive range of authentication systems. There are many



Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Fig. 6 BCI application fields

Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface, Table 8 Summary of various studies (in decreasing order of accuracy) (Jayarathne et al. 2017)

Author(s)	Channels	No. of subjects	Task	Derived or extracted feature	Classifier	Avg. accuracy
Rui-Blondet et al.	3	50	Visual simulation of 400 images	Event-related potentials (ERP)	Normalized cross-correlation	100%
La Rocca et al.	64	108	Relaxation with opened eyes and closed eyes	Power spectral density (PSD), spectral coherence (COH)	Mahalanobis distance-based classifier and match-score fusion	100%
Chen et al.	16	29	Rapid serial visual presentation (RSVP)	Point-biserial correlation coefficients, Fisher's transformation	Linear discriminant analysis (LDA)	100%
Palaniappan	6	6	5 tasks: relaxation, math activity, geometric figure rotation, mental letter composition, visual counting	Auto-regressive coefficients (AR), spectral power (SP), inter-hemispheric power differences (IHPD), inter-hemispheric linear complexity (IHLC)	LDA	100%
Ashby et al.	14	5	4 tasks: relaxation, limb movement, geometric figure rotation, visual counting	AR, SP, IHPD, IHLC, PSD	Support vector machine (SVM)	100%
Chuang et al.	1	15	7 tasks: breathing, simulated finger movement, sport activity, singing/ passage recitation, audio listening, color identification, and pass-thought	Cosine similarity of the vector representation	k-Nearest neighbor (k-NN)	99%
Palaniappan	61	20	Drawing of common objects as visual simulation	Multiple signal classification (MUSIC)	k-NN, Elman neural network (ENN)	98%
Riera et al.	4	–	Relaxation	AR, fast Fourier transform (FFT), mutual information, coherence, cross-correlation (EEG and ECG data)	Fisher discriminant analysis (FDA)	98%
Jayarathne et al.	14	12	Imagining four-digit number as cognitive task	Common spatial patterns (CSP)	LDA	97%
Liew et al.	8	10	Apprehension of images as visual simulation	Coherence, cross-correlation, mean amplitude	Fuzzy-rough nearest neighbor (FRNN)	92%
Yeom et al.	18	10	Apprehension of images of faces including self-face as visual simulation	Difference of average signals, positive/ negative peaks at specific latencies	Nonlinear SVM classifier	86.1%

researches about brain signal patterns and using them as a person authentication. Electroencephalogram (EEG) signals are the most popular method in this process. A couple of different approaches are presented in this way to capture EEG signals and classify them with different classification methods to find the unique signals and use them as an authentication method with more accuracy.

Chen et al. (2016) proposed a system within authentication, which is centered on rapid serial visual presentation (RSVP) stimulus. A brain amplifier was used to obtain EEG signals and linear discriminant analysis (LDA) to classify them. A specific association constant calculated the important features. According to the author's notation, a password can be hidden effectively in certain compulsive situations.

Chuang et al. (2013) presented a new approach which used the MindWave to obtain data. Seven tasks were executed, including sports activity, breathing, audio listing, simulation of finger movement, color, reciting and identifying music with singing, and pass-thoughts. The classification process is done with the k-nearest neighbor (k- NN) algorithm. The most accurate strategies were for color, audio, and sport. The most difficult one was for the pass-thought task according to the results of the questionnaire that determined user-friendliness with different tasks. Breathing, audio, and color were the straightforward tasks.

La Rocca et al. (2014) presented an approach centered around connectivity within EEG spectral coherence. In this method, data samples were gathered from 108 participants during open resting and closed eyes positions. EEG data was captured using a system consisting of 64 different channels with a rate of 160 Hz. Data was filtered to 50 Hz via a low-pass anti-aliasing filter. Spectral coherence (COH) and power spectral density (PSD) analysis techniques were used to extract mental features. To calculate uniqueness, two different algorithms were used separately in this process which were Mahalanobis classifiers that were based on distance and match-score fusion system. This technique is strong and very accurate for user identification. The performance of classification has the possibility of not functioning properly if this classification was used for a larger group of users on traditional hardware and it is less than 100%.

Ruiz-Blondet et al. (2016) presented a protocol known as CEREBRE with a band-pass filtering between 1 and 55 Hz, and based on normalized cross-correlation, a simple discriminant function was used for classification. The nominal (four categories, three channels) classifier showed the highest accuracy when all the patterns were used, but both maximum and minimum classifiers showed 100% accuracy. The results presented that the most accurate was for the stimulus oddball and food. The resting pattern had a reduced performance in terms of classification. Authentication centered on a memory-evoking task (also known as "pass-thoughts" in other studies) (Thorpe et al. 2005) also showed weak results; this is due to the inconstant time that was consumed to allow thinking.

According to the limitations of the methods which have been presented in the published papers and researches, the authors need better techniques like using different tasks and user strategies to acquire brain signals, better methods for preprocessing and feature extraction, and better classifiers to find the unique brain signal and use it as a new biometric authentication.

Conclusion

In the near future, biometric authentication methods will be the most useful methods for devices and applications for security because of the usability and security level and they are easier to use. However, there are some disadvantages for some methods. Brainwave is another human biometrics. There were some experiments using brain signals as an authentication method, which in some methods high accuracy is acquired. However, they had some limitations, which can be improved in the future.

Brainwaves are another human biometric that could be the most secure biometric technique. In comparison with other biometric techniques in terms of security, the human brain signal has a couple of important advantages. It is the only biometric that is changeable, it is not visible to

duplicate and does not have shoulder surfing problem, and it is more useful for disabled people in which a good example would be the famous scientist Stephen Hawking who was using a kind of brain-computer interface technology.

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Brain-Computer Interface

▶ Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface

Brawl

▶ Super Smash Bros.: A Brief History

B-Spline 3D Curves

▶ B-Splines

B-Spline Computer-Aided Design

▶ B-Splines

B-Spline Polygons

▶ B-Splines

B-Spline Surfaces

▶ B-Splines

B-Splines

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Synonyms

B-Spline 3D curves; B-Spline computer-aided design; B-Spline polygons; B-Spline surfaces

Definition

B-Splines are one of the most promising curves in computer graphics. They are blessed with some superior geometric properties which make them an ideal candidate for several applications in computer-aided design industry. In this entry, some basic properties of B-Spline curves are presented. Two significant B-Spline properties, viz., convex hull property and repeated points' effects are discussed. The B-Splines' computation in computational devices is also illustrated. An industry application based on image processing where B-Spline curve reconstructs the 3D surfaces for CT image datasets of inner organs further highlights the strength of these curves.

Introduction

Before the evolution of computer graphics, the aircraft wings and automobile parts were designed through splines. A spline constitutes long wood or plastic pieces of flexible nature where rectangular section is put in place at several positions using heavy lead weights commonly known as ducks. The duck places the spline at fixed positions with respect to the drawing board (Beach 1991). This helps spline to take the natural shape considering ducks. The spline's shape can be changed through ducks' movement. This has several drawbacks such as duck positions recording, drafting equipment required towards complex parts, consumer costs, absence of closed form solutions, etc. (Buss 2003).

As such, polygons give good rendering. But a better way is required towards generating the curved surfaces. For a designer, it is difficult to manipulate directly billions of polygons which make up the rendered model. A general way is required to specify arbitrary curved surfaces that can be converted to rendering polygons. For this, a mechanism is required which allows to specify any smooth desired curved surface. The solutions are generally provided by three categories of surfaces, viz., Bézier surfaces, B-Spline surfaces, and subdivision surfaces. In this direction, the computer-aided design industry uses NURBS surfaces as its standard definition mechanism. The visual effects industry uses both NURBS and subdivision surfaces. With the introduction of UNISURF which is a CAGD software tool by Pierre Bezier (https://en.wikipedia.org/wiki/Pierre_Bézier), the smooth curves can be easily projected on screens and monitors at low physical storage space. This resulted in the evolution of various CAD based software such as Maya, Blender, 3DMax, etc. This followed the development of a new mathematical structure called spline which is a smooth curve represented through few points.

With this motivation, in this entry, we present the basic properties which define the B-Spline curves. Some of the significant B-Spline properties discussed here are convex hull property and repeated points' effects. The computation task for B-Splines in computational devices is also highlighted. An industry application revolving

around image processing with B-Spline applications on 3D surface reconstruction towards inner organs taken from CT images further highlights the significance of these curves. This entry is organized as follows. Section "B-Splines: Overview" gives an overview of the B-Spline curves with computation task for these curves. This is followed by an industry application involving image processing with B-Splines. Finally, the conclusions are given.

B-Splines: Overview

The B-Splines are highly capable for describing various forms of curves (Chaudhuri 2018). They form a special case for splines, to be more specific the Bezier curves generalization. They are constructed with orthonormal basis of recursive functions. They comprise of curves which are of polynomial nature at points which are basically knots. The polynomial's degree is identical to that of B-Spline. The cubic segments form an important part of B-Splines. Such curves are known as cubic B-Splines. Now we present some B-Splines along with certain examples highlighting the special scenarios.

Considering a, b, c coordinates with respect to parameter t, B-Spline can be represented as: $a = a(ts)$, $b = b(ts)$, $c = c(ts)$. For B-Spline parametric curve, there exists certain discontinuities for parametric functions at parameter values which depict the knots. For B-Spline, there are several polynomial curve sections as control points number minus polynomial's degree. Considering N control points and n^{th} degree polynomial, there exists $(N - n)$ sections. The joining of these sections happens at $(N - n - 1)$ knots. For control points $\overline{cp}_i; i = 1, \ldots\ldots, N$ with $\overline{cp}_i = \langle x_i, y_i, z_i \rangle$. For polynomial curve's dimensionality connecting knots being n, then B-Spline's parametric equation is:

$$\bar{V}(ts) = \sum_{k=1}^{N} BS^{n}_{(k-1)}(ts)\overline{cp}_k \; ts_n \leq ts \leq ts_N, \quad N \geq n+1 \tag{1}$$

The knots should have parameter values ts along with them. The ts values at knots are represented as ts_{j+n} considering knot joint of $j^{th}$and $(j + 1)^{th}$ polynomial segments. This is in addition to the parameter values ts_n and ts_N which correspond towards start and end for complete curve. There are also $2n$ parameter values $ts_0, \ldots\ldots, ts_{n-1}$ and $ts_{N+1}, \ldots\ldots, ts_{N+n}$ values which are associated blending polynomials. The values ts_j are monotonically increasing values which may be either equally spaced, integers or positive.

The functions $BS^n_k(ts)$ are recursively defined as:

$$BS^n_k(ts) = \frac{ts - ts_k}{ts_{k+n} - ts_k} BS^{n-1}_k(ts) + \frac{ts_{k+n+1} - ts}{ts_{k+n+1} - ts_{k+1}} BS^{n-1}_{k+1}(ts) \tag{2}$$

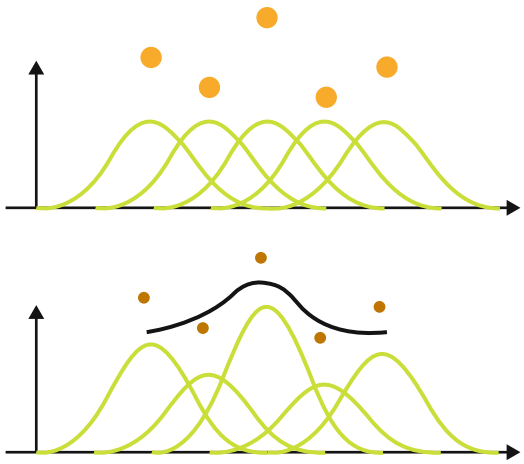
With unit step function being defined as:

$$us(ts) = \begin{cases} 1 & ts > 0 \\ 0 & ow \end{cases} \tag{3}$$

The 0^{th} order polynomial BS is:

$$BS^0_k(ts) = us(ts - ts_k)us(ts_{k+1} - ts) \tag{4}$$

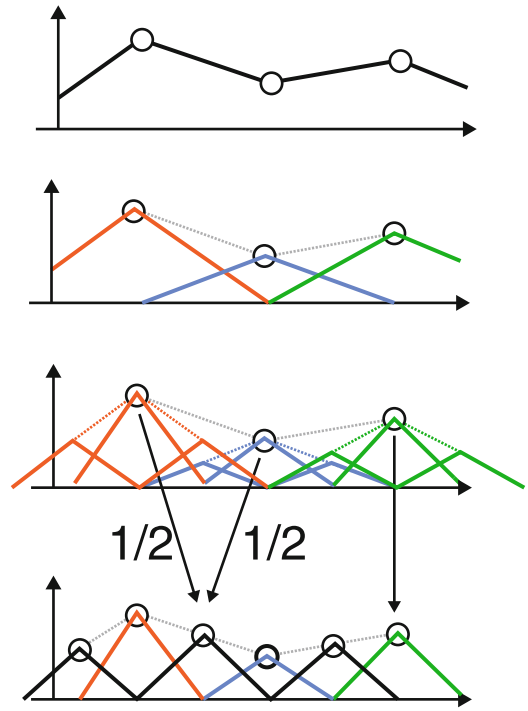
It is to be noted that $BS^n_k \neq 0$ considering range $ts_k < ts < ts_{k+n+1}$. Figure 1 illustrates



B-Splines, Fig. 1 Some representative B-Spline curves

some B-Spline curves. The B-Splines are basically characterized by the following properties:

(a) They can easily be represented through piecewise polynomial. This allows a B-Spline curve to be represented as a linear combination of number of B-Splines. Any B-Spline curve can be refined as linear combination of piecewise segments as shown in Fig. 2. The curves can also be refined through linear operation on control points.
(b) The unit integral can effectively represent a B-Spline as: $\int_{-\infty}^{+\infty} BS_k(ts)d(ts) = 1$.
(c) They are nonnegative in nature such that: $BS_k(ts) \geq 0$.
(d) B-Splines always partition of unity: $\sum_j BS_k(ts - j) = 1$.
(e) They are highlighted through the support factor: $BS_k(ts) \neq 0$, $ts \in [0, k]$.



B-Splines, Fig. 2 B-Spline curve refined as linear combination of piecewise segments

Now let us discuss some significant properties of B-Splines. The two important properties of B-Splines worth mentioning are the convex hull property and the effect of repeated points. The justifications are trivial in nature.

It is known that by recursion $BS_k^n > 0$, and it can also be shown for one n at a time. As a result of this, using recursion leads to:

$$\sum_{k=1}^{N} BS_{(k-1)}^n(ts) \equiv 1, ts_n < ts < ts_N \quad (5)$$

With this, B-Splines satisfy the convex hull requirements.

The B-Spline curve moves near the coordinate, when adjacent points of control have identical coordinates. Considering n identical adjacent control points, the spline interpolates the point.

Next, we consider the case where integer knots are equally spaced. Let us consider $ts_k = k$, then from the above equations we have:

$$BS_k^0(ts) = us(ts - k)us(k + 1 - ts) \quad (6)$$

$$BS_k^n(ts) = \frac{ts - k}{n} BS_k^{n-1}(ts) + \frac{k + n + 1 - ts}{n} BS_{k+1}^{n-1}(ts) \quad (7)$$

It is to be noted that $BS_k^0(ts) = BS_0^0(ts - k)$, such that by recursion $BS_k^n(ts) = BS_0^n(ts - k)$. Hence, for knots' integer spacing which results in B-Splines of uniform nature, only single blended polynomial is required towards each spline's degree.

Now some examples are highlighted for cubic B-Splines. The higher degree polynomials become:

$$BS_0^1(ts) = ts\{us(ts)us(1 - ts)\} + (2 - ts)\{us(ts - 1)us(2 - ts)\} \quad (8)$$

$$BS_0^2(ts) = \frac{1}{2}ts^2[\{us(t)us(1 - ts)\} + \{ts(2 - ts) + (3 - ts)(ts - 1)\}\{us(ts - 1)us(2 - ts)\} + (3 - ts)^2\{us(ts - 2)us(3 - ts)\}] \quad (9)$$

$$BS_0^3(ts) = \frac{1}{6}\left[ts^3\{us(ts)us(1-ts)\}\right.$$
$$+ \{ts^2(2-\mathrm{ts}) + ts(ts-1)(3-ts)$$
$$+ (ts-1)^2(4-ts)\}\{us(ts-1)us(2-ts)\}$$
$$+ \left\{ts(3-ts)^2 + (ts-1)(3-ts)(4-ts)\right.$$
$$+ (ts-2)(4-ts)^2\}\{us(ts-2)us(3-ts)\}$$
$$\left.+ \left\{(4-ts)^3 us(ts-3)us(4-ts)\right\}\right] \tag{10}$$

The graphical plots corresponding to the four lowest order blending polynomials are shown in Fig. 3.

With respect to the above equations, B-Spline can also be refined as linear combination of dilates and translates of the curve itself. This can be written recursively for $k = 0, 1$ as:

$$BS_0(ts) = BS_0(2ts) + BS_0(2ts-1) \tag{11}$$

$$BS_1(ts)$$
$$= \frac{1}{2}[BS_1(2ts) + 2BS_1(2ts-1) + BS_1(2ts-2)] \tag{12}$$

The above equations are represented through the curves shown in Fig. 4. Some of the refinement masks are also shown in Fig. 5.

The above equations are further generalized as follows:

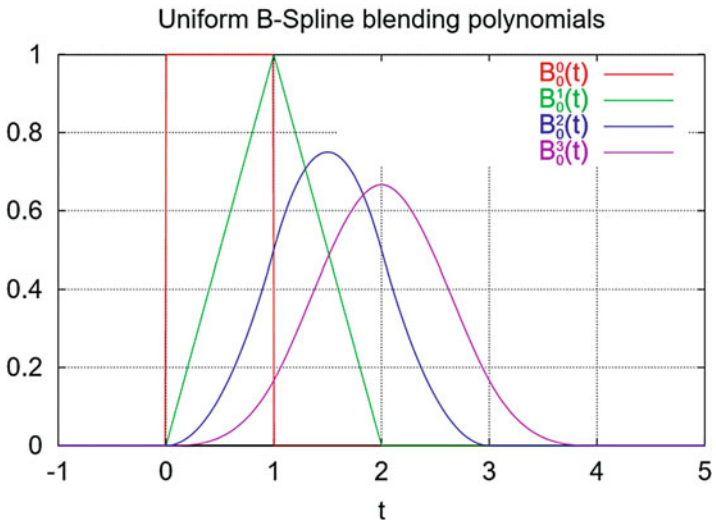
$$BS_k(ts) = \frac{1}{2^k} \times \sum_{k=0}^{n+1} \binom{n+1}{k} BS_k(2ts-k) \tag{13}$$

The subdivision operators can readily be applied on B-Splines. The subdivision works through bases and control points. Considering a B-Spline, subdivision operator S can be enforced such that:

$$BS(ts) = BS(2ts)S \tag{14}$$

The term S in above equation represents the subdivision matrix. Figure 6 represents a typical subdivision matrix. The subdivision operation is stationary in nature.

The subdivision can be successively applied on control polygon using control points' sequence. The subdivision in B-Splines leads the resulting curve to convergence, smoothness, and approximation. The subdivision matrix converges the curve towards cubic B-spline representation. This allows the control polygon to be drawn instead of the curve. Using an iterative refinement process, the curve approximation is achieved through several refinements as shown in Fig. 7.

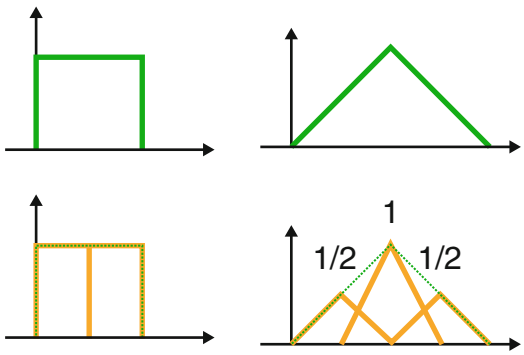


B-Splines, Fig. 3 The four lowest order blending polynomials corresponding to uniform B-Splines

The surface approximation is done using tensor product which is defined over regular quadrilateral meshes. Sometimes semi-regular quadrilateral meshes are used which have few sufficiently separated vertices. The semi-regular meshes represent the boundary surface of an object. In geometric modeling, patches of regular meshes are traditionally used and stuck together. But it becomes difficult towards handling patch density.

Computation Task for B-Splines

The B-Splines are generally computed through fast computing devices (Chaudhuri 2018) because small time steps are required by a smooth curve. To make the computations simple, the calculations are specified with respect to regular uniform B-Splines. Let us start considering the spline order. Considering the order as k, a set of n control points are specified. The number of points on the curve may vary depending on the smoothness desired by the user. These set of points are denoted as the curve set.

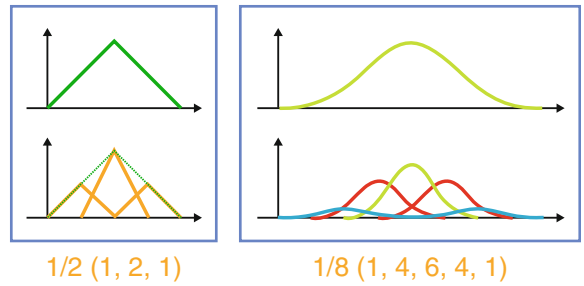


B-Splines, Fig. 4 The curves on left and right are represented through above equations

As the initial step, the uniform knot vector of length $n + k$ is considered. The calculation is performed as follows. Each knot is initialized as zero. Then considering each $1 < i \leq n + k$, it is required to be verified whether conditions $i > n$ and $i < n + 2$ are satisfied. If the conditions hold, then current knot takes the value of previous knot with an increment of 1 otherwise, the current knot considers the previous knot value. Now considering $k = n = 4$, the knot vector takes the value $\{0, 0, 0, 0, 1, 1, 1, 1\}$. Before calculating the curve set points, it is required to fix a correct step value for parameter *ts*. The step is reached by dividing knot's value considering one less than number of points on curve set.

Now we initiate the computing task towards curve set points for B-spline. Care should be taken such that the number of basis functions which are calculated for each time step is equal to that of number of points in control set. Thus considering the entire spline, number of basis computations is same as the product of magnitudes of control and curve sets. Hence for 20 points on curve set with 4 control points, 80 basis functions are required to be calculated.

At each step, Cox-de Boor algorithm is used in order to calculate the basis function's value. During each iteration through the steps, the entire knot vector is taken as with step value *ts*. It is observed that Cox-de Boor algorithm is recursive. As a result of this, care needs to be taken such that the basis is calculated correctly. When the set of n basis functions for control points at specified step *ts* is available, the curve points' coordinates are calculated by multiplying the i^{th} basis function to i^{th} control point. The values obtained are then embedded into curve set. This helps towards generation for collection of points which when plotted together as well



B-Splines, Fig. 5 The curves on left and right represent the refinement masks for $\frac{1}{2}(1,2,1)$ and $\frac{1}{8}(1,4,6,4,1)$

as connected with line segments resembles a curve. The number of calculations required to make B-spline are appreciably large.

Industry Application

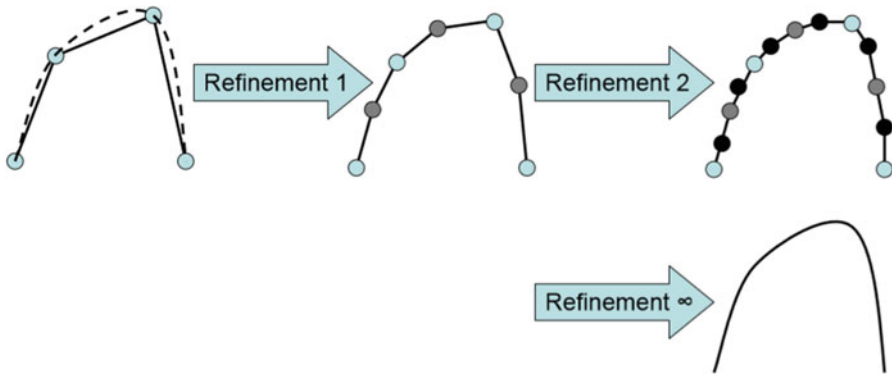
In this section, a novel industry application involving B-Spline surfaces with image processing is presented which is adopted from Ref. (Partyka 2014). The experimental dataset contains about 1900 images from the CT scan of the entire body. Only 500 images considering the chest and upper abdomen have been used for analysis. Here 3D surface is reconstructed for organs developed through tomography. It uses k-means clustering and Hu moments in order to filter contours considering the tomography frames. The least squares B-Spline fitting approximates filtered contours. The organ surface is approximated through B-Spline surface. The technique requires no human intervention. As such, high-quality surfaces in versatile format are created.

The contour selection process is a significant step in surface reconstruction. Each contour is selected with utmost care. Then noise is minimized such that resulting surface is not affected. Also, a high-fidelity product needs to be maintained. Here enhancement of each CT slice done and canny edge detector detects the contours. An empirical threshold for edge detector is set. The morphological operations and filtering for small contours is done to eliminate unwanted noise. The effects of filtering are presented in the second and third images for the Figs. 8, 9, and 10.

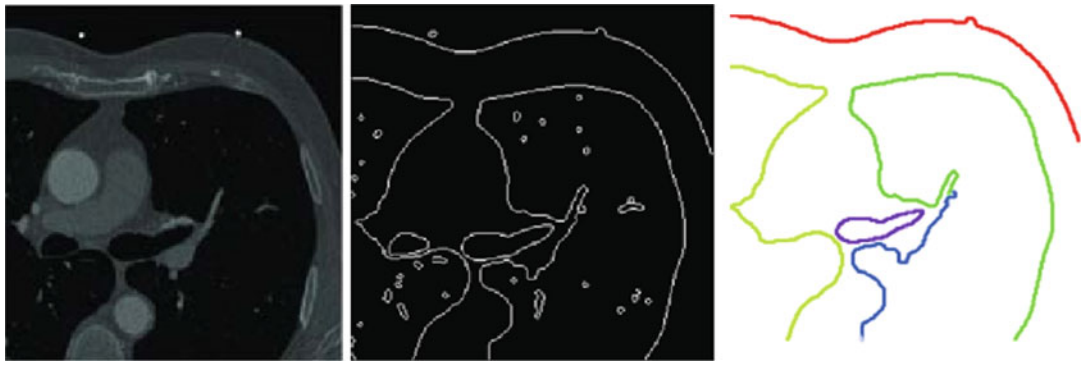
The unwanted contours are removed through automatic noise filtering where larger datasets are created using contour detection. The right lung is taken as region of interest (RoI). About 1996, contours covering chest, left lung, stomach, aorta, etc. are created through contour detection and filtering step. The right lung is selected manually from 450 images. Because of shape and contours location diversity, these contours are filtered through k-means clustering. To address the contour's shape, an n-dimensional vector is created which is composed of (X, Y) coordinates for contour's centroid and varying Hu moments. After detecting and prefiltering contours, clustering is done. Considering each contour, Hu

B-Splines, Fig. 6
A subdivision matrix

$$\mathbf{S} = \frac{1}{8}\begin{pmatrix}
\ddots & \vdots & \vdots & \vdots & \vdots & \ddots \\
\cdots & 1 & 0 & 0 & 0 & \cdots \\
\cdots & 4 & 0 & 0 & 0 & \cdots \\
\cdots & 6 & 1 & 0 & 0 & \cdots \\
\cdots & 4 & 4 & 0 & 0 & \cdots \\
\cdots & 1 & 6 & 1 & 0 & \cdots \\
\cdots & 0 & 4 & 4 & 0 & \cdots \\
\cdots & 0 & 1 & 6 & 1 & \cdots \\
\cdots & 0 & 0 & 4 & 4 & \cdots \\
\cdots & 0 & 0 & 1 & 6 & \cdots \\
\cdots & 0 & 0 & 0 & 4 & \cdots \\
\cdots & 0 & 0 & 0 & 1 & \cdots \\
\ddots & \vdots & \vdots & \vdots & \vdots & \ddots
\end{pmatrix}$$

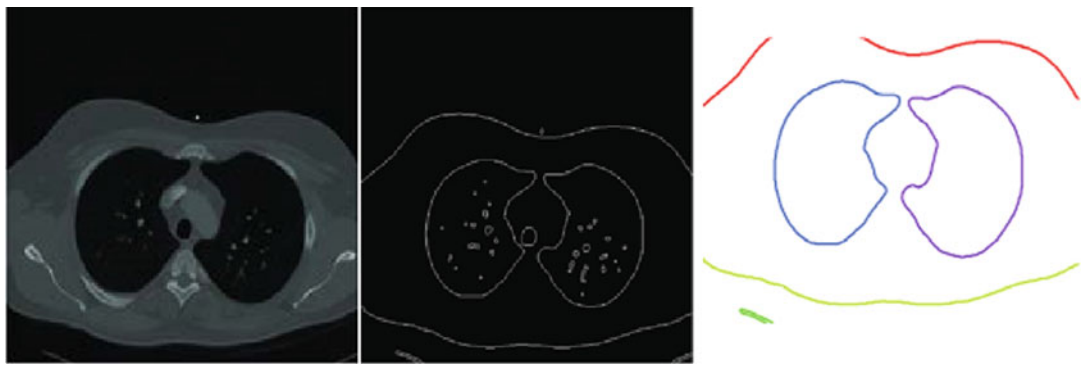


B-Splines, Fig. 7 The iterative refinement process on curves



B-Splines, Fig. 8 Images from first dataset (original image, detected edges, detected contours)

B-Splines, Fig. 9 Images from second dataset (original image, detected edges, detected contours)



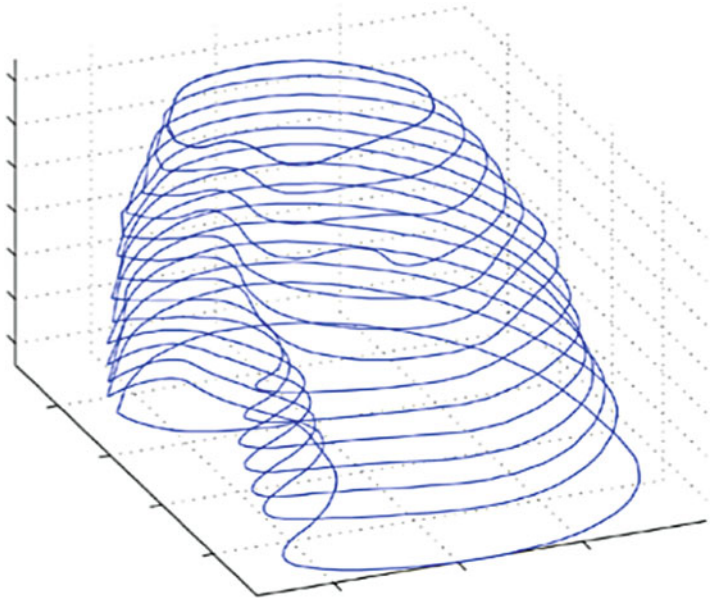
B-Splines, Fig. 10 Images from third dataset (original image, detected edges, detected contours)

moments and centroid are calculated which are used after normalization towards k-means clustering. These clusters are used towards examined contours classification considering Euclidean distance from cluster which represents RoI. The testing is done for all combinations of feature vectors based on contour centroid as well as its Hu moments. The best results are achieved through second Hu moment with respect to centroid coordinates.

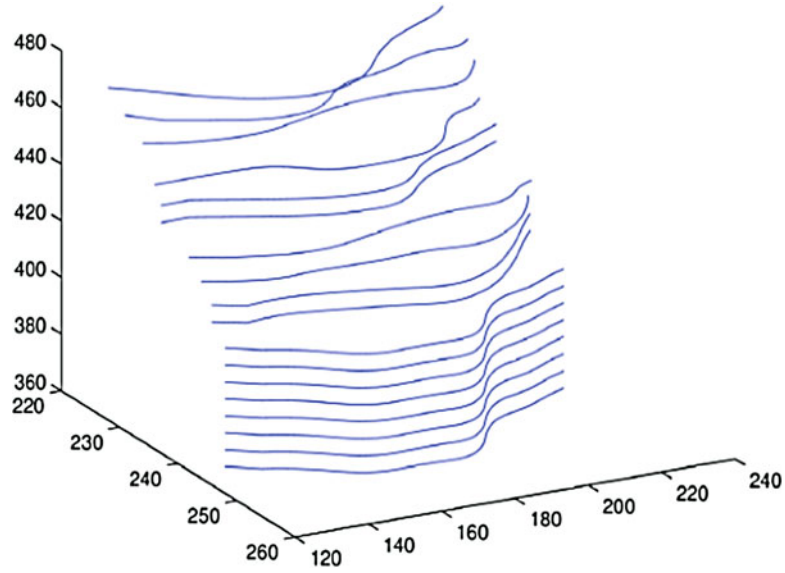
B-Splines, Fig. 11 The correctly classified contours

B-Splines, Fig. 12 The false +ves classified as contours

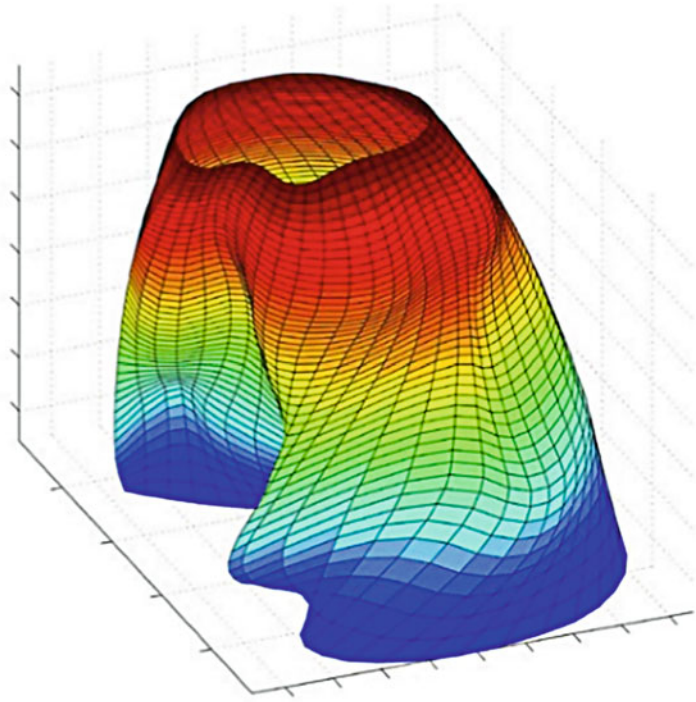
B-Splines, Fig. 13 The surface approximations through cross sections



The n-dimensional cluster centroids achieved during k-means are utilized towards segmenting the desired contours. Actually, good responses are received with 3D vectors where second Hu moment and (X, Y) coordinates for contour's gravity center are used. The experiments were done using 1996 labeled contours from which 450 are taken as right lung and others are ignored. Figures 11 and 12 show the correctly classified contours and false positives classified as contours, respectively. It is to be noted that second Hu moment



B-Splines, Fig. 14 The lung surface reconstructed through cross-section fragments



B-Splines, Fig. 15 The lung's twisted surface

alone with (X, Y) coordinates for contour's gravity center produces appreciable results. The 3D vector substantially reduces the calculations and yields faster and more responsive application.

After the contour segmentation, the algorithm is approximated and least-squares B-Spline fitting for every contour is done. The contour points in preceding algorithm steps are used towards fitting cubic B-Spline for every segmented contour cross section.

The curve points form the organ contour are in place and the control points are required to be computed. This can be represented as the following equation where CV, NB, and N denote the curve, orthonormal basis, and control points, respectively:

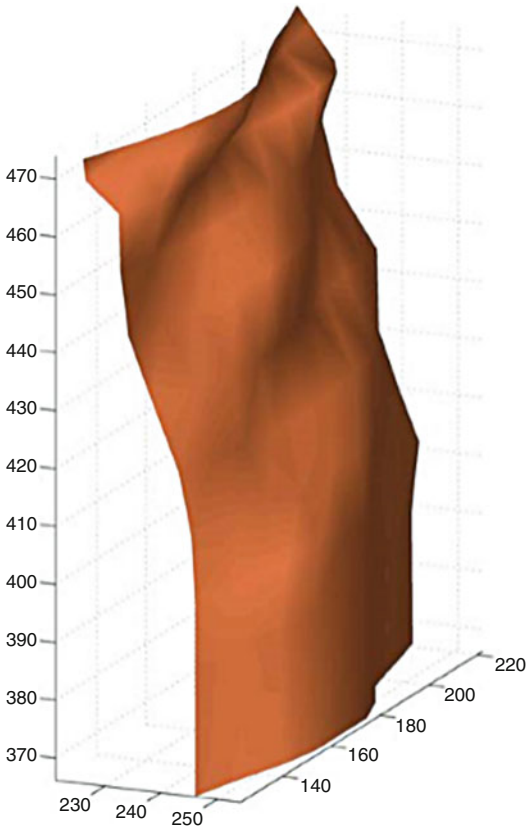
$$CV = NB \cdot N \tag{15}$$

The above equation can be solved towards N considering least squares such that:

$$N = \left(NB^T \cdot NB\right)^{-1} \cdot NB^T \cdot CV \tag{16}$$

The resulting N matrix comprises of control point vectors towards every cross section. To achieve a smooth surface, all approximated cross section splines are made compatible. They are required to have similar degree which is 3 here and need to be specified through identical knot vector. The common knot vector can be achieved by taking the average of the consequent knot vectors considering all the cross sections.

The control points for all cross-section curves are taken column by column and a second curves' family is fitted towards approximating these control points columns. This leads to second B-Spline curves family. The two control point vectors set forms control net for tensor surface which can be plotted. The control net and two knot vectors taken from each curve family completely define the surface. Figure 13 presents a fragment of right lung surface which is constructed using 3D points. Figure 14 presents a detailed view of lung fragment with ribs impression in lung surface. The appreciable results are obtained when cross-section contours are approximated through



B-Splines, Fig. 16 The lung surface being rendered considering cross sections

control points with third-degree B-Spline. The higher order curves look towards greater number of control points and produces curves which are prone with loops and wiggles.

Here there is no need for curve alignment. Figure 15 represents twisted surface. This does not imply any other problems, except slightly unpleasant visual effects. Figure 16 shows the lung surface being rendered considering cross sections.

Conclusion

In this entry, we have presented some of the important geometric properties of B-Spline curves. The properties worth mentioning are convex hull property and repeated points' effects. These curves find superior applications in computer-aided design industry. The computation

of B-Splines' in computational devices is also highlighted. An industry application on image processing with B-Spline curve for reconstructing the 3D surface for CT image datasets of inner organs further justifies the importance of these curves.

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C

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Call of Duty Franchise, an Analysis

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Synonyms

Esports; First-person shooter

Definitions

First-person shooter (FPS) = a genre of games where the camera is in a first-person viewpoint. Players make use of guns to eliminate targets and/or secure other objectives.

Esports = A sports competition with video games as the focus rather than traditional sports.

History of Call of Duty

As of 2016, the *Call of Duty* series as a whole has sold 250 million copies and five of the games have made the top 50 best-selling video games of all-time list (McWhertor 2016). The first title released in the first-person shooter *Call of Duty* series was *Call of Duty: Finest Hour*. *Finest Hour* was released on October 29, 2003. The series started as a Microsoft exclusive and it ran on the IW game engine. Today, one can find *Call of Duty* on any console or handheld device. Activision-Blizzard currently owns the series. From 2006 until 2014, there was a rotation every year between two different developers, Infinity Ward and Treyarch. In that time span, Infinity Ward developed the titles such as *The Big Red One*, *Modern Warfare 1–3*, and *Ghosts*. Treyarch, on the other hand, developed *World at War*, *Finest Hour*, and *Black Ops 1 & 2*. In 2014, a new company took on the mantle and developed the *Call of Duty* title for that year as well as being added to the rotation. Sledgehammer developed the game *Advanced Warfare*. The games developed since then have been Treyarch with *Black Ops 3*, Infinity Ward with *Infinite Warfare*, and Sledgehammer with *World War 2*. All titles in the series have an ESRB rating of M (ESRB 2021).

Call of Duty, being a franchise about war, is usually set in a war zone. *Call of Duty* has been set in the past as well as the future. *Call of Duty* has also brought some real-life events to the game. In the most recent game, the developers brought the

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N. Lee (ed.), *Encyclopedia of Computer Graphics and Games*,
https://doi.org/10.1007/978-3-031-23161-2

invasion of Normandy into the game with a new game mode. *Call of Duty* is adapting to the current game market by creating their own battle royale mode called "Blackout." *Call of Duty* is also known for its Zombies game mode, where players are tasked with surviving against increasingly difficult waves of zombies with up to three other players.

Some similar FPS games to *Call of Duty* are *Halo*, *Battlefield*, *CSGO*, and *Rainbow Six Siege*. These games are played by people of all ages, but according to surveys 31% of *Call of Duty* players are between the ages of 25 and 34 (Knezovic 2021).

Call of Duty also has its own line of comic adaptations. The "Official Comic of Call of Duty®: Black Ops 4" is a ten-issue series introducing the iconic Specialists of the Black Ops Universe. The game also inspires a number of short films. In 2015, Activision announced the creation of a cinematic universe based on the *Call of Duty* franchise with a first film projected to be released in 2018 or 2019, and directed by Stefano Sollima. However, in an interview in 2020, Stefano Sollima stated that films were "no longer a priority for Activision" (Delaney 2020).

More importantly, however, *Call of Duty* burst into the esports scene in 2006 following the release of *Modern Warfare*. Activision-Blizzard hosts their own World Championship where the top teams compete each year. The Call of Duty League was launched in 2020, featuring the world's greatest professional players. As of 2021, the lineup of COD 2022 teams includes Atlanta FaZe, Florida Mutineers, London Royal Ravens, LA Guerrillas, LA Thieves, Minnesota Rokkr, New York Subliners, OpTic Texas, Paris Legion, Seattle Surge, and Toronto Ultra. The original 12 teams became 11 teams due to the merger between Dallas Empire and OpTic Chicago to form OpTic Texas. The most famous COD professional player is Chris "Simp" Lehr who has earned over $546,000 in *Call of Duty* tournaments despite being only 19 years old. He plays for the Atlanta FaZe team (Lionade Games 2021).

Cross-References

▶ First-Person Shooter Games, a Brief History

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Cellular Automata

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▶ Lattice Boltzmann Method for Fluid Simulation
▶ Lattice Gas Cellular Automata for Fluid Simulation

Cellular Automata Methods

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C

Synonyms

Numerical methods; Physics simulation

Definitions

Cellular Automata
Mathematical models based on simple and local rules capable of generating complex behaviors.

Introduction

In his articles collection about Cellular Automata, specifically in the article entitled *Cellular Automata* from 1983, Wolfram (1994) introduces the subject with a reflection on the basic laws of physics relevant to everyday phenomena. Many of these laws involve complex systems, composed of numerous components, each obeying simple rules, so that the complex behavior of the studied phenomenon can be obtained. To discover and analyze the mathematical basis of complex systems, it is necessary to identify simplified mathematical systems that are capable of capturing the essence of the process, and the Cellular Automata are strong candidates in this matter.

Cellular Automata are mathematical models based on simple and local rules capable of generating complex behaviors. They were originally introduced by John von Neumann, under the name of cellular spaces, as an idealization of biological systems, with the particular aim of modeling systems capable of self-reproduction (Sarkar 2000).

In 1940, John von Neumann was involved in the planning of the first digital computers. His

goal was to obtain complex behaviors through simple rules for spatial interactions and temporal evolution. It would be a machine analogous to the human brain whose processing and memory units were not separated from each other, massively parallel and capable of self-reproduction (Chopard and Droz 1998).

Following suggestions by S. Ulam, John von Neumann proposed a discrete universe based on a two-dimensional lattice, whose cells are interconnected locally to one another. Each cell is characterized by an internal state, representing a finite state machine. Through a local rule of evolution, each cell updates its state in function of its own and the states of some neighboring cells. All cells of the lattice evolve according to the same local rule, which makes the system homogeneous, like many physical and biological systems. These cellular universes proposed by John von Neumann are now known as Cellular Automata (Chopard and Droz 1998; Kari 2005).

In the cellular automata proposed by Neumann (1966), a neighborhood formed by the four nearest neighbors (north, south, east, west) and 29 possible states for each cell was defined for each two-dimensional cell of the lattice. The theory of Cellular Automata was consolidated with the work of Burks (1970) and underwent a considerable simplification in Codd's work (1968).

Wolfram's researches (1994) became the pioneer author in the work with Cellular Automata as mathematical models for the study of the phenomenon of self- organization. He suggested the use of one-dimensional automata, each cell having as its neighbor the left and right cells and a set of two possible states.

Martin used polynomial algebra tools to deduce the characterization of uniform cellular automata (identical rules applied to each cell of the automaton) with a periodic boundary (Martin et al. 1984). A new era of research began in 1992 with the work on analytical characterization of the behavior of automata based on matrix algebra tools. The technique proposed in (Das et al. 1992) is able to characterize hybrid cellular automata (different rules applied to different cells) with periodic or zero frontiers.

Many papers had their interests focused on applications of automata to computing and biology. However, in the last decades, there is also considerable interest in the field of physics (Daniel 1994). In particular, models based on cellular automata for fluids have been developed, such as the Lattice Gas Cellular Automata (LGCA) (Frisch et al. 1986), electromagnetic models, such as Ising Spin Models, and models for diffusion phenomena (Weimar et al. 1991).

According to Wolfram (1994), physical systems that contain discrete elements and whose interactions occur locally can be modeled through the use of Cellular Automata. Although they are defined by simple local rules, automata can display complex dynamic behaviors on a wide scale. Such rules can be seen as a simplification of the microscopic dynamics, which reproduce the expected macroscopic behavior. For example, on a microscopic scale each cell can represent a particle of the system.

Several authors have been directing their lines of research for the understanding and application of Cellular Automatics. According to (Chopard and Droz 1998), some of these lines involve the use of automaton models for the simulation of physical and biological systems. The success obtained in these applications lies in the fact that Cellular Automata possess several fundamental properties of the physical world: they are massively parallel, homogeneous, and all interactions occur locally. Other physical properties such as reversibility and conservation laws can be programmed through an appropriate choice of local evolution rule.

Formal Definition

In a formal way, a Cellular Automata is a quadruple:

$$A = (L; S; N; f),$$

where L is a set of indices or cells; S is the finite set of states, that is, of the possible values that each cell can assume; $N : L \rightarrow L^k$ is the mapping that defines the neighborhood of each cell i as a collection of k cells; and $f : S^k \rightarrow S$ is the evolution function or the update rule of the automaton

(Wolfram 1994). The *f* rule is responsible for the overall dynamics of the Cellular Automaton and is applied at every instant of time in all cells. The collection of cell states at any time step is called the configuration or global state of the automaton (Chopard and Droz 1998).

Neighborhoods

An *f* update rule for an automaton is a local rule, since it only depends on the state of neighboring cells. At first there is no restriction on the size of a neighborhood. In practice, however, it is common to use only adjacent cells (Wolfram 1994). For Cellular Automata, two neighborhoods are considered: a **von Neumann Neighborhood** and **Moore's Neighborhood** (Chopard and Droz 1998).

The simplest von Neumann neighborhood consists of a central cell, which is exactly the cell to be updated by rule *f*, and its four geographic neighbors north, south, east, and west (Chopard and Droz 1998). Generalizing, (Wolfram 1994) defines the von Neumann neighborhood of radius r of cell $\mathbf{x^0}$ as:

$$N^v(\mathbf{x^0}) = \{\mathbf{x} : \|\mathbf{x} - \mathbf{x^0}\| \leq r\}, \quad (1)$$

where $\| \cdot \|$ is the norm of the sum.

For two-dimensional Cellular Automata, the definition (1) is given by:

$$N^v(x^0, x^0) = \{(x_1, x_2) : |x_1 - x_1^0| + |x_2 - x_2^0| \leq r\}. \quad (2)$$

Figure 1 shows a von Neumann neighborhood for two-dimensional automata.

In addition to the four geographic neighbors cited in the von Neumann neighborhood (north, south, east, west), Moore's neighborhood also contains the four diagonal neighbors (north-east, north-west, south-east, south-west) (Chopard and Droz 1998). Such neighborhood of radius r for cell $\mathbf{x^0}$ is defined by (Wolfram 1994) as:

$$N^v(\mathbf{x^0}) = \{\mathbf{x} : |x_i - x_i^0| \leq r, i = 1, \ldots, d\}, \quad (3)$$

where d is the space dimension and x_i is the i-th space component.

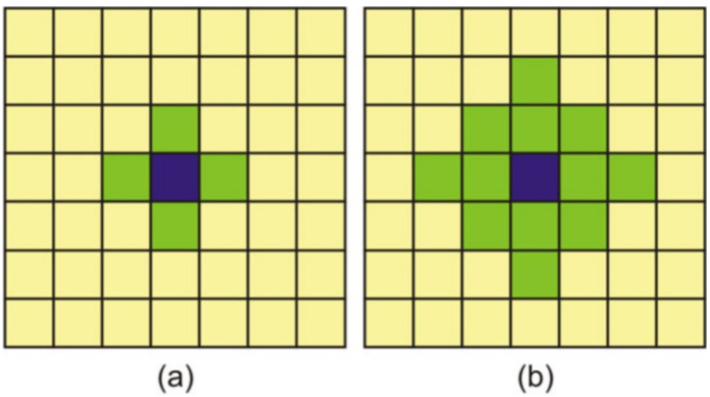
For two-dimensional automatas ($d = 2$), the definition (3) is given by:

$$N^v(x_1^0, x_2^0) = \{(x_1, x_2) : |x_1 - x_1^0| \leq r, |x_2 - x_2^0| \leq r\}. \quad (4)$$

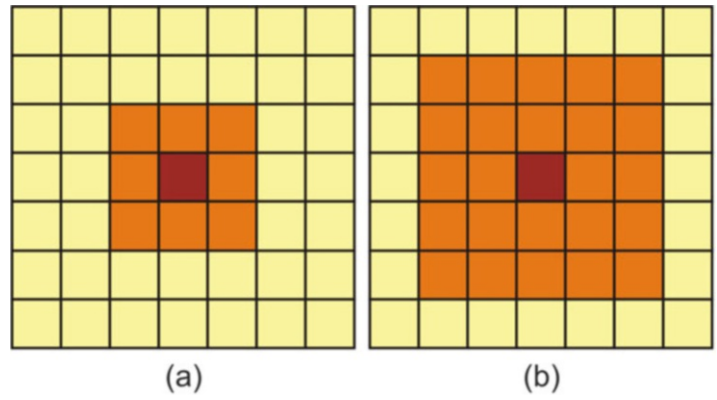
Figure 2 shows Moore's neighborhood for two-dimensional automatas.

Boundary Condition

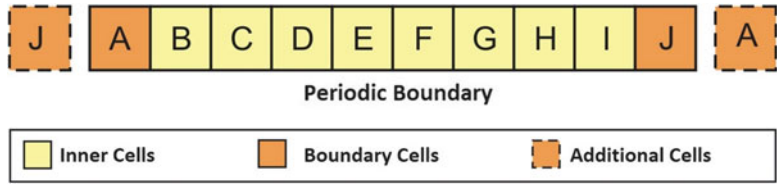
In practice it becomes impracticable to work with an infinite lattice. Once the boundaries of the lattice are defined, it is clear that the cells present at the border will not have the same neighborhood as the inner cells. It is therefore necessary to identify which cells belong to the border and apply different rules to them. Following this methodology, it is possible to define several types of



Cellular Automata Methods, Fig. 1 A von Neumann neighborhood for two-dimensional automata: (**a**) $r = 1$, (**b**) $r = 2$



Cellular Automata Methods, Fig. 2 Moore's neighborhood for two-dimensional automata: (**a**) $r = 1$, (**b**) $r = 2$



Cellular Automata Methods, Fig. 3 Periodic boundary condition for unidimensional automata

borders, each with a different behavior (Wolfram 1994). However, instead of defining distinct rules for frontier cells, another possibility is to extend the neighborhood to these cells. A widely used solution is the periodic boundary condition, which assumes that the lattice is embedded in a torus-type topology. Such a condition is obtained by extending the lattice periodically, as shown in Fig. 3. In the case of a two-dimensional automata, the periodic boundary condition assumes that the right and left sides are connected, as well as the upper and lower part of the lattice (Chopard and Droz 1998).

Other types of boundary conditions add a set of cells along the boundary, as shown in Fig. 4a–c (Chopard and Droz 1998). The fixed boundary condition defines predefined values for these new cells. The adiabatic frontier condition doubles the value of the cells that are at the border for the additional cells. The reflective boundary condition copies the value of the cell next to the border cell to the additional cell.

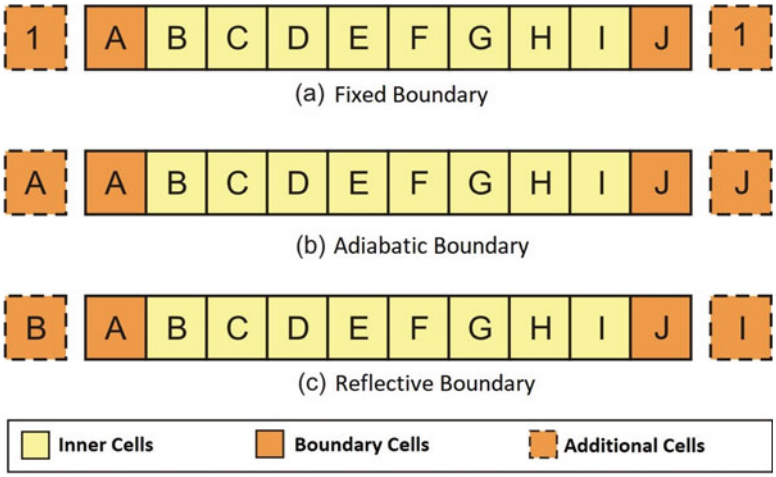
Choosing which type of boundary condition to use will depend on the nature of the problem being modeled. In some cases, a combination of more than one type of condition can be used, for example, in the simulation of a long channel, where one can use horizontal periodic boundary and the vertical reflective one (Chopard and Droz 1998).

Classification

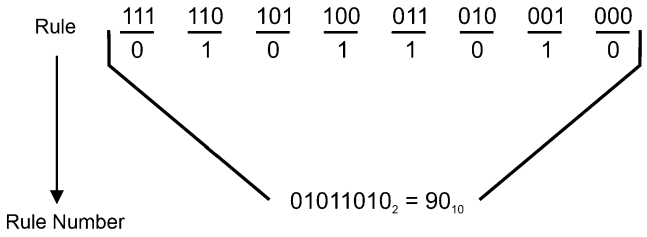
A unidimensional Cellular Automata with the set of possible states defined by $S = \{0, 1\}$ and ray neighborhood $r = 1$ is called **elementary** (Kari 2005). In this configuration, there are $2^3 = 8$ possible combinations in the vicinity of a given cell, where each of these combinations can be mapped in 0 and 1. Thus, there are $2^8 = 256$ different Elementary Cellular Automata (Kari 2005). These elementary rules were studied and classified by Wolfram (1994), who introduced a methodology to name them: each of these elementary rules is specified by a sequence of eight bits,

$$f(111)f(110)f(101)f(100)f(011)f(010)$$
$$f(001)f(000),$$

where f is the automaton update rule. The bits sequence is the binary expansion of an integer in the range of $0 \ldots 255$, called **Wolfram Nomenclature** of the Cellular Automata (Wolfram 1994; Kari 2005).


1 A B C D E F G H I J 1
(a) Fixed Boundary
A A B C D E F G H I J J
(b) Adiabatic Boundary
B A B C D E F G H I J I
(c) Reflective Boundary
Inner Cells
Boundary Cells
Additional Cells

Cellular Automata Methods, Fig. 4 Boundaries condition: (**a**) Fixed, (**b**) Adiabatic, and (**c**) Reflective



Cellular Automata Methods, Fig. 5 Wolfram Nomenclature

The numerical value that will identify the rule is obtained by combining the values resulting from applying the update rule f to each of the eight possible neighborhoods, thus forming a binary number. The representation of this number in the decimal base gives the numerical value for the rule (Kari 2005). For example, Fig. 5 shows the process of identifying the cellular automaton with $r = 1$, known as Rule 90.

Examples of dynamics of one-dimensional Cellular Automata are often represented in a spatiotemporal diagram. Horizontal lines are consecutive configurations, and the top line is the initial configuration. For example, Fig. 6 shows diagrams of Rule 110 on two different scales, where black represents the state 1 and white the state 0 (Kari 2005).

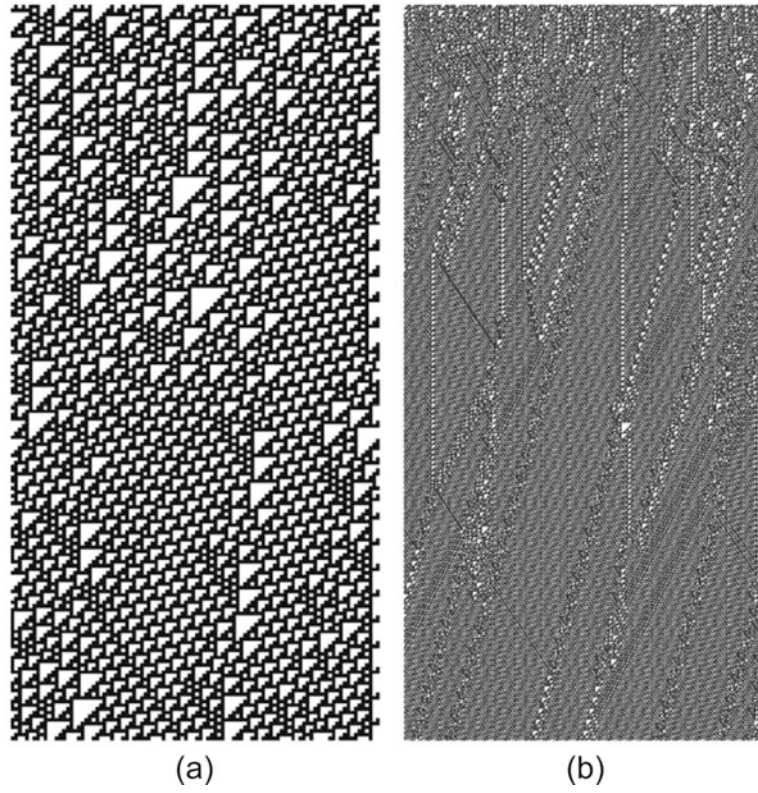
Wolfram (1994) did numerous experiments with rules of Elemental Cellular Automata using random initial configurations. Based on the types of spatial-temporal diagrams observed, he classified the rules into four categories (Chopard and Droz 1998; Kari 2005), namely:

- **Class 1**: The evolution of the automaton leads to a homogeneous state in which, for example, all cells have 0 value (Fig. 7a);
- **Class 2**: The evolution of the automaton leads to a set of stable or periodic structures, which are simple and separate (Fig. 7b);
- **Class 3**: The evolution of the automaton leads to a chaotic pattern (Fig. 7c);
- **Class 4**: The evolution of the automaton leads to complex structures (Fig. 7d).

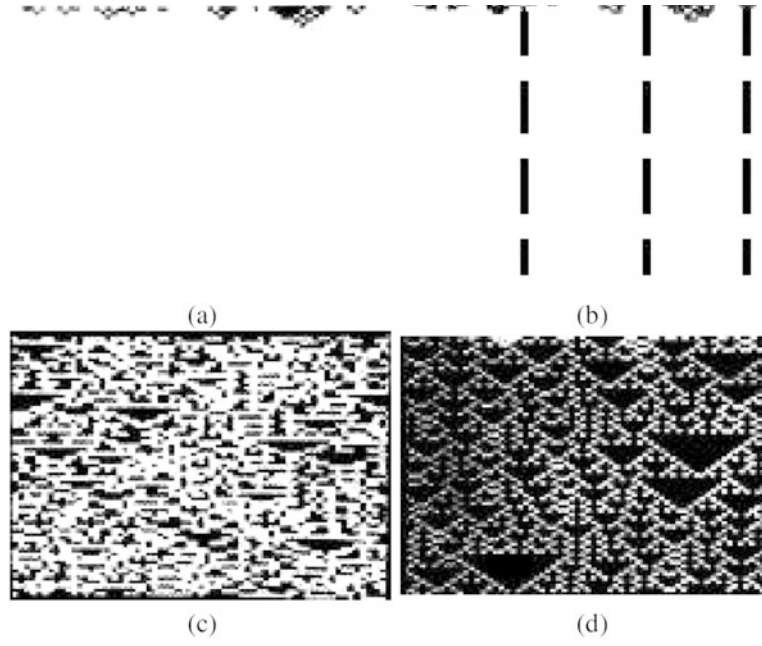
The existence of only four classes implies a considerable universality in the behavior of cellular automata. Many characteristics of a given automaton depend only on the class in which it belongs and not on the details of its evolution.

Examples of Cellular Automata

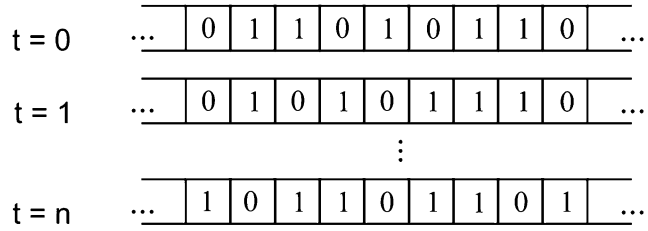
Using the traditional nomenclature (Sarkar 2000), at each time step, the collection of cell states is called the **configuration** or **global state** of



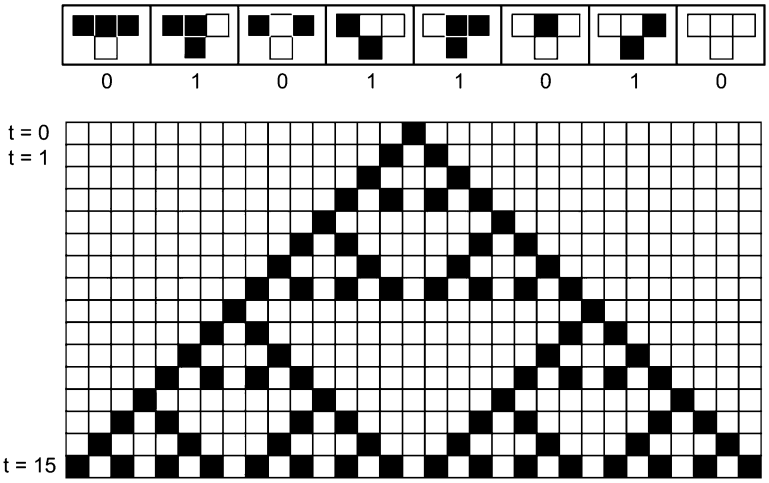
Cellular Automata Methods, Fig. 6 Space-time diagrams of Rule 110



Cellular Automata Methods, Fig. 7 Spatiotemporal diagrams: some examples of Wolfram's classification



Cellular Automata Methods, Fig. 8 Evolution of one-dimensional Cellular Automaton



Cellular Automata Methods, Fig. 9 Cellular Autamata Rule 90. Evolution after 15 time steps

the automaton. In the initial step $t = 0$, we have the initial configuration, and as time increases, the local rule is applied on all cells, as (generically) represented in Fig. 8 for one-dimensional case. Similar definitions are made for two-dimensional cases.

Rule 90

The Cellular Automata Rule 90 consists of an one-dimensional vector, whose set of possible states is formed by $S = \{0, 1\}$ and the update rule f is the binary sum of neighboring cell states (Wolfram 1994). Thus, given a cell x_i at instant t, its state a_i^t is defined by:

$$a_i^t = a_{i-1}^{t-1} \bigoplus a_{i+1}^{t-1}, \tag{5}$$

where $\bigoplus$ is the binary sum.

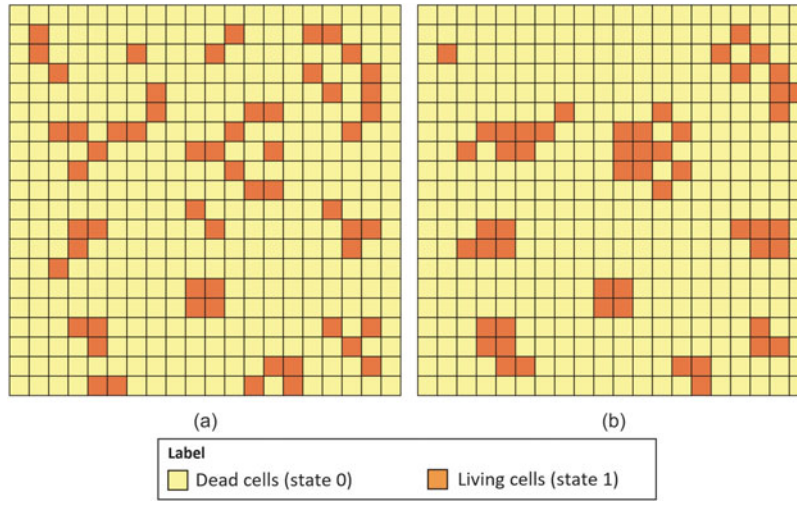
At the top of Fig. 9 we have the eight possible configurations for the neighborhood of the cell to be updated and the result of the binary sum effected. Below we can see a spatiotemporal diagram after 15 steps of evolution.

It is interesting to note that, starting from a simple initial configuration, where only one initial cell has state 1 and the others have state 0, after 15 steps already it is possible to observe the formation of a nontrivial pattern.

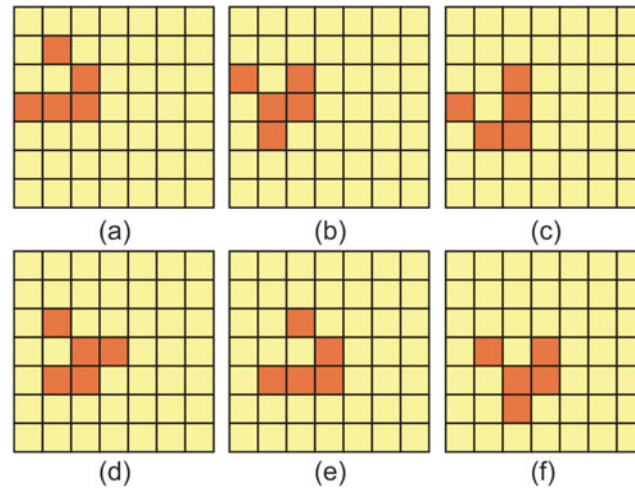
Game of Life

In 1970, the mathematician John Conway proposed the famous Game of Life (Gardner 1970). His motivation was to find a $2D$ automaton that would generate complex behaviors (Chopard and Droz 1998). The Game of Life consists of a two-dimensional lattice, where each cell can contain the 0 or 1 values. For this set of states, Conway classified the cell in vivo, if it contains the value 1, or dead, to the value 0. This automaton uses the Moore's Neighborhood (Kari 2005).

The update function f seeks to simulate an artificial life, based on the following rules:



Cellular Automata Methods, Fig. 10 Game of life: (**a**) initial step, (**b**) step 1



Cellular Automata Methods, Fig. 11 Gliders at Game of Life: (**a**) initial step, (**b**) step 1, (**c**) step 2, (**d**) step 3, (**e**) step 4, (**f**) step 5

- A cell whose state is 0 and which has exactly three living cells in its neighborhood passes to the state 1.
- A cell whose state is 1 and which contains less than two living cells in its neighborhood passes to the state 0.
- A cell whose state is 1 and which has in its vicinity more than three living cells passes to the state 0.

Figure 10 shows an example of Game of Life in a 20 × 20 lattice.

The Game of Life has a very rich behavior. During the evolution process of the automaton, it is possible to notice the emergence of complex structures, such as the so-called gliders, shown in Fig. 11. Gliders are specific cell configurations which have the property of moving around in space. We can observe in Fig. 11 that the configurations (e) and (f) are translations of configurations (a) and (b), respectively.

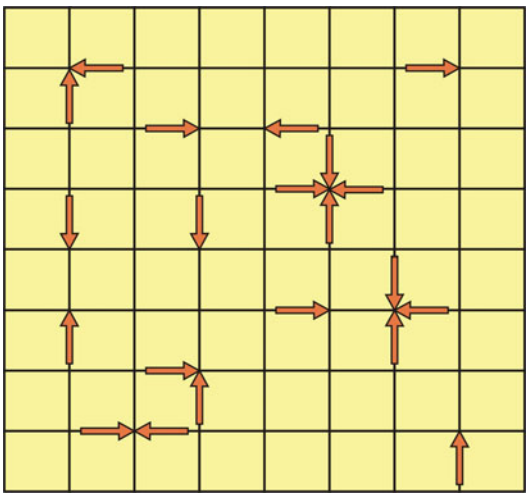
HPP Model

The HPP model is part of a group of specific Cellular Automata, called Lattice Gas. It was developed by Jean Hardy, Olivier de Pazzis, and Yves Pomeau in the 1970s. His proposal is to

model fluids via cellular automata, using simple and local rules that mimic a particle dynamics. The essential characteristics of the actual microscopic interactions that are taken into account are the laws of conservation of the linear momentum and conservation of the number of particles (Chopard and Droz 1998).

The HPP is defined in a two-dimensional lattice, and the basic idea of its dynamics is to work with particles that move along the directions of the lattice, following appropriate rules. The set of possible states is composed of $S = \{0, 1\}$ and represents the absence or presence of particles. Figure 12 shows an example of a configuration of the HPP particles.

By definition, Cellular Automata work with a finite number of bits to represent the state of each cell. Therefore, in order for the molecular dynamics of the HPP to be compatible with the automata's dynamics, there must be a restriction of the quantity of particles present simultaneously in a given cell (Chopard and Droz 1998). Such a constraint is called **Principle of Exclusion** which guarantees that, given a lattice cell, there can only be at most one particle incident in a given direction of motion, at a given instant of time. Thus, four bits of information for each cell are sufficient to describe the system during its evolution.

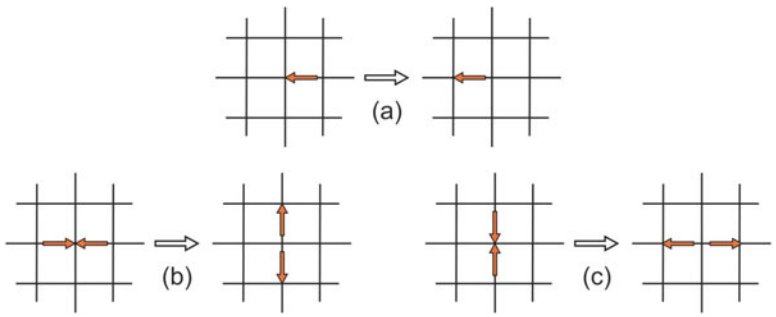


Cellular Automata Methods, Fig. 12 Particles configuration example in HPP model

The HPP update rule consists of two steps: collision and propagation (Chopard and Droz 1998). The collision phase specifies the interaction between particles entering the same lattice node. It is at this stage that the particles are "rearranged" in different directions, in order to ensure that the exclusion principle is satisfied, as shown in Fig. 13b–c. In propagation phase, each particle moves to the neighboring cell, in the direction corresponding to its direction of motion, as shown in Fig. 13a.

The purpose of the HPP rule is to reproduce certain aspects of actual interactions between particles, such as the conservation of momentum and the amount of particles. Looking for Fig. 13b–c we can observe that during the collision process a pair of particles with null moment along a given direction is transformed into another pair of particles, also with the null moment, moving on the perpendicular axis.

Another important feature in the HPP model is invariance under time reversal (reversibility). At any given moment, if the direction of movement of all particles is reversed, the system will recover



Cellular Automata Methods, Fig. 13 HPP Rules: (**a**) Propagation, (**b, c**) Collision

its entire history. This property becomes a limiter when the intention is to use the model to describe a real fluid, since in this case there is the presence of viscosity. Other limitations are related to algebraic invariants of the adopted lattice (Wolfram 1994).

Cross-References

- ▶ Fluid Simulation
- ▶ Lattice Gas Cellular Automata for Fluid Simulation

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Centralized Architectures

- ▶ Client/Server Gaming Architectures

Cerebral Palsy

- ▶ Computer Games for People with Disability

CG

- ▶ Planetary Generation in Games
- ▶ Postproduction in Game Cinematics

CG, Computer Graphics

- ▶ The New Age of Procedural Texturing

Challenge-Based Learning in a Serious Global Game

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Synonyms

Collaborative problem solving; Contextual learning and teaching; Learning challenges; Open-ended problem-based learning; Project-based learning

Definition

Challenge-based learning offers a call to action that inherently requires learners to make something happen. In a serious game context

learners often work in teams in a digital game-based platform to research their topic, brainstorm strategies and solutions that are both credible and realistic in light of time and resources, and then develop and execute a solution that addresses the challenge in ways both they themselves and others can see and measure. Teams often compete with each other for high scoring solutions, recognition, and rewards. For example, a business might offer an "X-Prize" for a solution needed for driverless cars. Challenge-based learning can thus be seen as a way to incentivize crowd-sourced ideation and solutions.

Introduction

The term challenge-based learning arose in the USA early in the twenty-first century with the support of innovative technology groups such as Apple Education, the New Media Consortium, The Society for Information Technology and Teacher Education, and the US Department of Education Office of Educational Technology. Unique applications supporting challenge-based learning in higher education are now arising, supported by a cloud-based mobile technology platform that can be used for bridging informal to formal learning, recruiting students into university, reaching larger numbers of people with game-based approaches, envisioning student engagement in work-integrated learning, and assisting students to acquire evidence of attainment of graduate capabilities such as leadership, critical thinking, creativity, communication skills, and experience in international team collaboration (Gibson et al. forthcoming, 2018a, b).

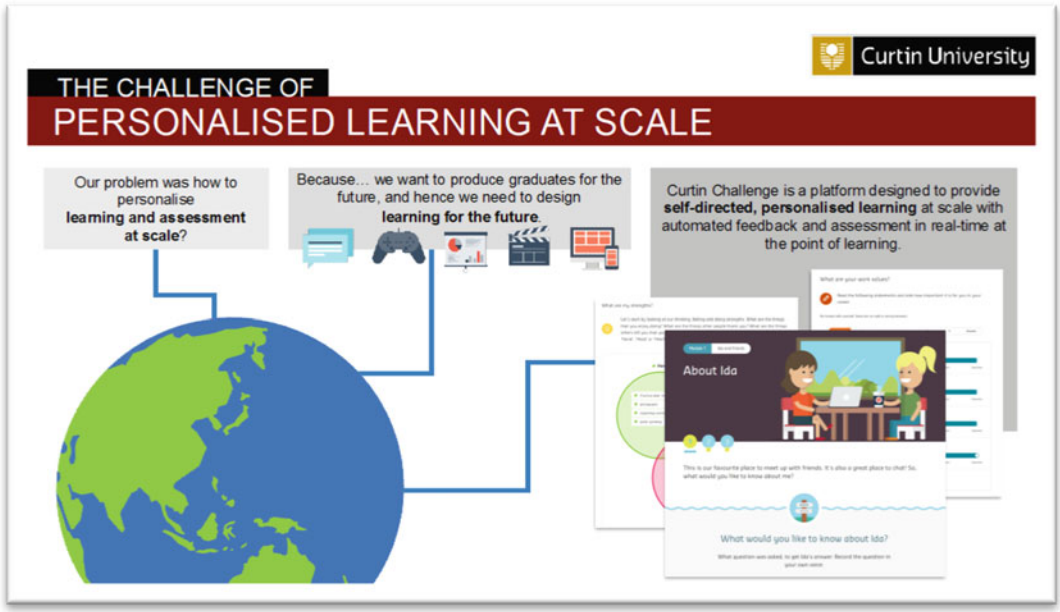
State of the Art Work

Challenge-based learning is a teaching model that incorporates aspects of collaborative problem-based learning, project-based learning, and contextual teaching and learning while focusing on current real-world problems (Johnson et al. 2009). In particular, online global learning challenges engage students' curiosity and desire to learn by making central the solving of open-ended problems as a member of a self-organizing and self-directing international team (Harris and Nolte 2007). When delivered as a mobile learning experience, challenges can integrate twenty-first-century tools, require collaboration, and assist students in managing their time and work schedules, while effectively scaling to large numbers of students. Set in the environment of a friendly serious game competition where people experience elements such as automated feedback, points, leader boards, badges, and leveling up for rewards, challenge-based learning increases motivation toward high performance (Gibson and Grasso 2007). Research on challenge-based learning is beginning to show impacts such as increased engagement, increased time working on tasks, creative application of technology, and increased satisfaction with learning (Johnson et al. forthcoming, 2018; Roselli and Brophy 2006).

Similar to problem-based and project-based learning, and borrowing liberally from those well-established approaches (see Gibson et al. 2011) and the Buck Institute for Education (www.bie.org), the additional structure of global relevance, international collaboration, and team-based competition leads to a unique objective, expressed well in a recent report by the New Media Consortium (Johnson et al. 2009).

Design and Implementation Roles

The design method for the future of challenge-based digital learning experiences is a team-based effort of people knowledgeable in subject matter, dramatic narrative, mechanics of game-like interactions and rewards, digital-media artists and communicators, and computational science tools for algorithms and visualizations (Gibson et al. 2007). The mission of such interdisciplinary teams when creating challenge-based learning experiences is to create a symbolic space for transmedia narrative (Passalacqua and Pianzola 2011) to be introduced as well as to evolve through the participatory culture (Jenkins et al. 2006) shared by those who take up the challenge.


Curtin University
THE CHALLENGE OF
PERSONALISED LEARNING AT SCALE
Our problem was how to personalise learning and assessment at scale?
Because... we want to produce graduates for the future, and hence we need to design learning for the future.
Curtin Challenge is a platform designed to provide self-directed, personalised learning at scale with automated feedback and assessment in real-time at the point of learning.
About Ida
What would you like to know about Ida?

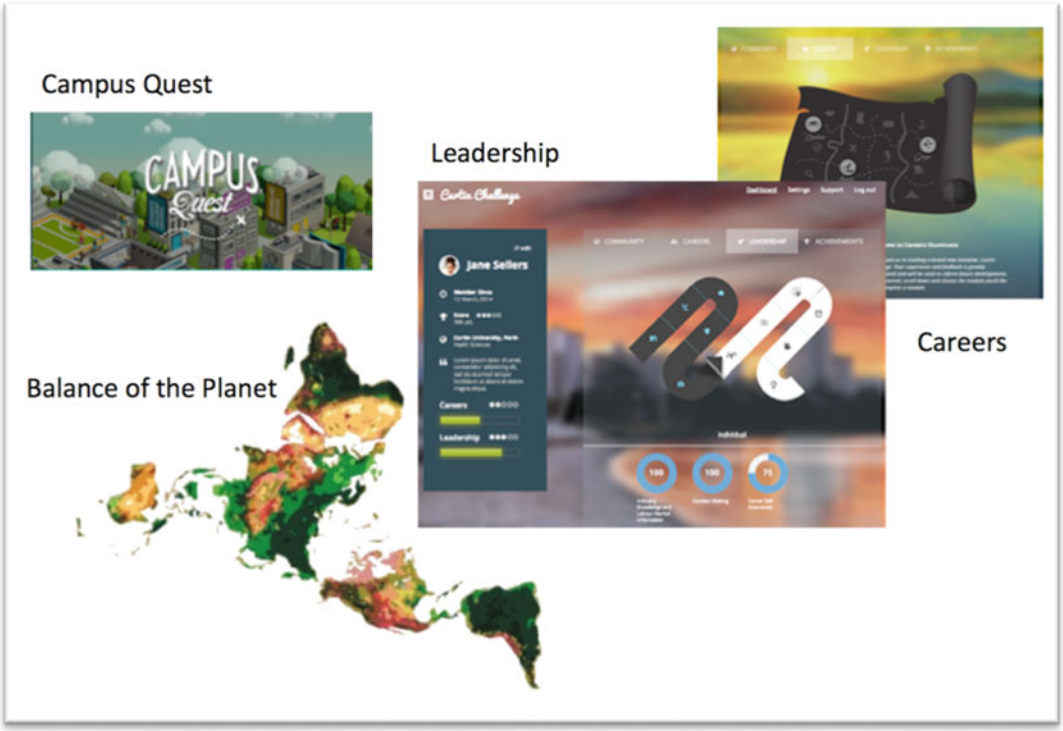
Challenge-Based Learning in a Serious Global Game, Fig. 1 Curtin Challenge platform as a solution to personalizing learning at scale

Instructors have a special role in constructing a problem space with key ideas, essential questions, resources, and evaluation criteria. In the challenge-based learning framework, instructors are designers of the digital-learning experience who put in most of their time in up front and then take a backseat during the implementation while individuals and teams are learning, working, communicating, creating, and submitting artifacts. Subject matter experts (SMEs) in a discipline work with a digital-media team and game-creation team to engineer the learning experience. Most of the input from subject-matter-expert authors is gathered during the design phase and is embedded into the digital experience through public scoring rubrics, artifact descriptions for final submission, and scaffolding activities, which the team members can choose to experience or ignore. A new structure of teaching, created via collaborations among SMEs working with learning-experience designers and technical teams, is arising as an innovation to create new structures of teaching and learning in response to the myriad changes taking place in higher education today (Grummon 2010).

Show Case

At Curtin University, in Perth Australia, a "Challenge platform" online toolkit has been developed to assist with authoring and delivering challenge-based individual and team learning at scale (Fig. 1). The platform can be compared to a game-engine marketplace with a common API for learning outcomes across the various learning experiences. Individual challenges include learning about oneself as a leader or exploring a career and team challenges available in "Balance of the Planet" including solving one or more of the UN Sustainable Development Goals (Fig. 2).

The platform roadmap includes features that support individual- and team-based learning in a serious game context:



Challenge-Based Learning in a Serious Global Game, Fig. 2 Individual and team-based challenges provide a serious game context for learning

- Self-organizing teams
- Self-determined paths of action
- Transparent milestones for seeing progress
- Self-scoring and peer scoring of artifacts
- Expert scoring for awards and recognition
- Openness to external mentors and advisors helping solve problems
- Automated feedback on progress
- 24-7 access
- Support tools for chatting, coproduction, and automated messaging
- Administrative dashboard for research data and monitoring

Cross-References

► Game-Based Learning (GBL)

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Challenges Facing the Arab Animation Cinema

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Synonyms

Arab animation; Arab cinema; Arab filmmakers; Muslim filmmakers; Political communication; Visual culture

Definition

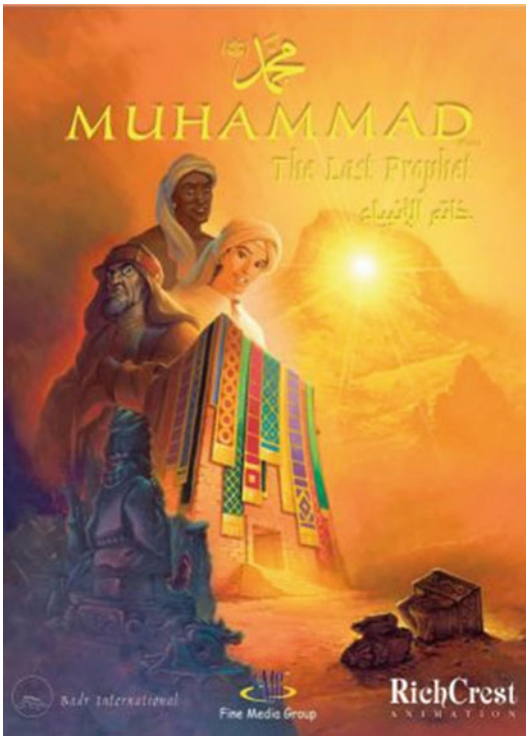
Arab filmmakers attempt to export their animated films to an international market and try to speak to other global cultures. They seek to build a bridge between the Arab world and the West through animated films which have been adapted from Arab and Islamic sources, but speak to the universal human condition. The relationship between Islam and the West, though, remains very complicated; the West looks at these projects and already has a perspective about them as religious and ideological propaganda, especially after 9/11, 2001. Thus, the majority of these Arabic animated films are rejected by the West because of concerns that these films represent the unwelcome principles of foreign cultures. Inherently, there is an Islamophobia about Islamic cultural products as soon as they come to the West; there is suspicion of them and extensive interrogation of them. Ironically, when Western artifacts are exported to Arab countries, though almost inherently at odds with Muslim ideology and Muslim politics, they sometimes find distribution and audiences. The consequences of this relationship between Arab countries and the West is not only ideological, however, and also concerned with the fact that Arab filmmakers and producers face economic challenges, and a number of Arab animation studios went out of business or stopped making more feature animated films due to the difficulties of reaching international marketplaces. Thus, the focus of contemporary Arab animation is mostly low-budget projects distributed through YouTube and social media, which became the main platform for Arab animation artists to distribute their political works during the "Arab Spring" in Tunisia, Egypt, Libya, Yemen, Syria, and elsewhere in the Middle East since 2011.

Introduction

After 9/11, Arab animation producers struggle to screen their films at cinemas in Europe and the USA. The irrational fear of Arabs and the Islamic religion [has] increased in the West, and Muslims have become targets of increased hostility, creating the now so-called Islamophobia. (Kalin 2011). The first use in print of the term Islamophobia was in the report of the Commission on British Muslims and Islamophobia in 1997 (Iqbal 2010). This

commission was established in 1996 by the Runnymede Trust, an independent research and social policy agency. The report was called *Islamophobia: A Challenge for Us All* and describes the main features of Islamophobia and the challenge it poses to Muslim communities. It covers central topics about Muslim communities and concerns in Britain, media coverage, violence, and building bridges by intercommunity projects and dialogue. The report also contains many subtopics separately from the main text, such as diversity and difference within Islam, perception of Islam as a threat, opposition to immigration, and other topics. Moreover, the report shows statistical tables of Muslim issues such as residential patterns, employment and unemployment, population in some cities in Britain, and incidents seen as racially motivated. The commission distributed more than 3,500 copies to government departments, organizations, social communities, universities, and the media.

The report defined the term Islamophobia as "the practical consequences to such hostility in unfair discrimination against Muslims individual and communities, and to the exclusion of Muslims from mainstream political and social affairs" (Runneymede Trust 1997). Islamophobia has affected Muslim film producers' capacity to show their Arab/Islamic animated films to a Western audience. For example, a Saudi film production company called Badr International invested around 12 million US dollars, which is the highest budget for any Arabic animated film so far, in their first feature animated film, *Muhammad the Last Prophet* (2002) (Jammal 2012). These movies were made by a team of artists from Hollywood who combined traditional hand drawing with computer graphics and effects. The director who had the unique experience and challenge of making this movie was Richard Rich, who worked for Disney for many years. The soundtrack was composed by Emmy-award winning composer William Kidd. In consequence, the movie was described as being an "(old-fashion) Western-style entertainment about a distinctly non-Western subject" (Stevens 2004). However, this movie was the first feature-length animated film that focused on the biography of the prophet



Challenges Facing the Arab Animation Cinema, Fig. 1 *Muhammad: The Last Prophet* (2002) (Directed by Richard Rich)

Muhammad and the journey with his followers from Mecca to Madina, set around 1400 years ago during the early years of Islam (Fig. 1).

There were two versions released of the feature and the short films, one in the Arabic language and one dubbed in English hoping to gain the attention of non–Arabic speaking audience. Badr made an agreement with many companies and cinemas to distribute and screen the film *Muhammad the Last Prophet* in the USA. However, the film's production finished at around the same time of 9/11 in 2001. The consequence was that most of the agreements were cancelled by US cinemas and distributors due to Islamophobia. Badr held the film for 2 years without screening it in cinemas. They did not want to sell the film's DVD to the market before the theatrical release. Later, a new Arabic distribution company based in the USA called FineMedia arranged a theatrical release in 37 US cities with Eid al-Fitr in 2004. The venture was not successful and revenues were very small.

Therefore, Badr International stopped making any more animated films and went out of business in animation field.

Limited Resources and Release

The bibliography related to animation in the Arab world is very limited, and it was hard to find published materials related directly to the subject; only two published references relating to Arab animation were found: the first one being *Cartoons: One Hundred Years of Cinema Animation* by Giannalberto Bendazzi (1994) and the second, the booklet *Animation in the Arab World, A glance on the Arabian animated films since 1936* by Mohamed Ghazala (2011).

Bendazzi's book covers the history of animated films assessing over 3,000 films in more than 70 countries worldwide. Nevertheless, the book covers only 3 of 22 Arab countries and contains only small animated productions from Egypt, Tunisia, and Algeria. Most of those Arab animation productions were TV series and TV commercials, and a few made as short films. An electronic communication was arranged with Bendazzi (2012) to ask what the reasons were for having such a small selection of Arab animation in his book (Bendazzi 2012). Bendazzi's first sentence was "I think you will be disappointed by my answers"; this sentence immediately gives a negative impression about Arab animation cinema and the challenges it faces.

Bendazzi points out that when he was writing the book, from 1983 to 1988, it was hard to find Arab animated films due to the lack of connections at that time such as internet, e-mails, and social network websites. In addition, Bendazzi faced language difficulties communicating with Arab film historians and filmmakers. Moreover, Arab critics did not pay attention to animation films.

In contrast to all the challenges that face Arab animation, and the small number of animation productions compared with the Western animation productions, the Arab world is abundant with magnificent folktales such as the *One Thousand and One Nights* stories which are suitable for adaptation to make into many animated films. From the inspiration of the *Arabian Nights* stories Western film producers have developed animated films such as *The Adventures of Princes Achmed* (1925), *Aladdin* (1992), and *Azur and Asmar* (2006). Arabs, however, have not used their own past Arabian stories to reach either the domestic and international animation marketplaces. Bendazzi recalls:

> Arab animators should participate to the great international festivals; watch the masterpieces of ten, twenty, seventy years ago, and read translated books. They first must be great animators with a distinctive style, and only then adapt any text from any literature. (Bendazzi 2012)

The Arab animation industry needs people with strong skills in animation techniques and process such as character design, animation, editing, lighting, compositing, sound, music, and marketing, and then start thinking about making successful animation feature films to screen to the Arab audience and then export these films to the international audience. However, one of most important parts of any successful film in the contemporary era is the story; the film would be good as soon as the story is good. Also, quality could come in different method and ways; it does not have to imitate Disney and Pixar styles. The Arab filmmakers should think of using contemporary tools and creating fresh and unique styles such as the Iranian animated films *Persepolis (2007)* and the documentary *The Green Wave* (2011). Thus, the Arab filmmaker should focus more on making universal stories with different styles in order to show them to audiences all around the world.

In March 2012, an invitation has been received from the *Cairo International Film Festival for Children (CIFFC)* to present my short animated film *Missing*. The CIFFC, organized by the Ministry of Culture in Egypt, is one of the biggest children's film festivals in the Arab region. There were more than 100 short and long feature live-actions, documentaries, and animated films at the official competition. Most of them were international productions and few were from Arab filmmakers, and there were no Arabic feature length animated films. This shows the limited amount of animated short and feature film productions in Arab countries.

During the festival, an interview was arranged with one of the festival's jury committee, Dr. Mohamed Ghazala (2012), the author of *Animation in the Arab World*: *A Glance on the Arabian Animated Films Since 1936*, the sole booklet on the market about Arab animation history. Ghazala is also the founder and director of the regional African and Arabian chapter of the *International Association of Animation Filmmakers* (ASIFA). The aim of this organization is to involve Arabic and African animation filmmakers in creating, developing, and promoting their own regional identity and having an impact in the international animation market by participating in festivals and setting up some animation workshops.

Ghazala notes that the booklet is a collection of five articles about Arab animation published in a South Korean animation magazine called *Animatoon* in the Korean language. Every two months, he covered the animation in different areas of the Arab world such as Egypt, North Africa, the Ash-sham area, and the Gulf area. Subsequently, he collected the five articles with some editing then presented them as a conference paper at *Athens Animfest Animation Festival* in 2011 in Greece. The booklet contains only 56 pages and includes a small filmography of Arab animation with some valuable data that is important to any researcher interested in Arab animation.

Ghazala explains the reasons behind the small selection of Arab animation in his booklet; he collected those Arab animated films individually by himself. The main problem was that he could not find any official archive or library for Arab animation. It was hard to find the original copy of the animated films, and few Arab animated films are available on the internet, and then, only with low resolution. Ghazala points out the problems of Arab animation films in terms of quantity and quality compared with the Western animation productions:

> I have attended many international animation festivals as a filmmaker or jury member; unfortunately, there were hardly any Arab animation in those international festivals. There is no systematic approach to producing and educating animation in the Arab region, most of the experiments that happened by the Arab animation filmmakers to show their Arabic identity and culture through animation are independent and without serious support from the Arab governments. Most of the high quality animation productions in Arab countries such as Egypt, Jordan, Tunisia and Morocco focus on TV commercials and TV series especially for Ramadan, and don't have interest in producing artistic films for cinema and festivals. You can only see the graduation projects by the Arab art students, who make artistic animation films, then after the graduation, they work in the industry to produce commercial works and the artistic work is disappearing quickly. (Ghazala 2012)

Arab film productions focus more on making live-action films. For example, in Egypt, "The Arab Hollywood," there had been produced thousands of live-action films (Shafik 2007). Surprisingly, Al Sahar Studio, one of the biggest animation studios in Egypt, has had financial difficulties since 1998 in attempting to complete their first Egyptian feature length animated film *The Knight and the Princess* (Ghazala 2011). Therefore, it is appropriate to question the reasons why there have been so few animated feature films successfully produced in the Arab world; Is it because the Arab film producers think that animation is only for television and children? Ghazala points out that for a long time, Arab national television has imported all the animation films and TV series that suited children:

> When I was a kid I thought that the animation is only *Walt Disney's* productions. When I grew up, a friend gave me a video tape of animated films produced in the Czech Republic, which has completely different style than the films we used to watch in our national televisions. These Czech animated films were abstract, artistic and nice stories. In that time I realized that animation could be for kids and adults. The Arab did not screen the East European animated films that were produced in the 60s and the 70s in the cinemas and television; these films could inspire the Arab of making such artistic animation films. (Ghazala 2012)

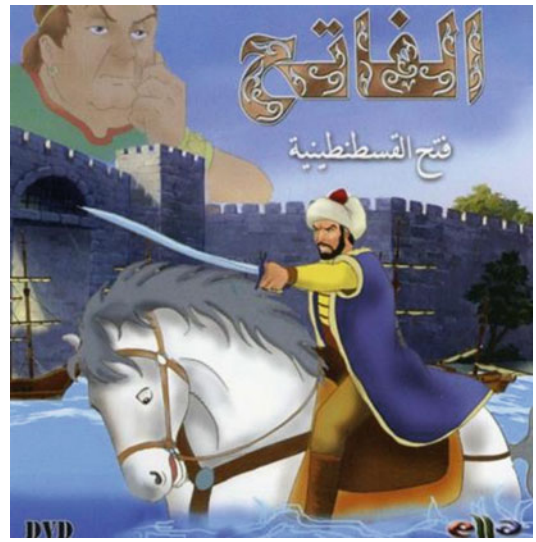
Another challenge facing Arab animation is the lack of animation academies in the Arab region; many universities have Arts schools that focus on graphic design and the fine arts, but only a very few schools teach animation. In addition, there are a few animation festivals in some Arab counties

such as the Cairo Children's Film Festival in Egypt, the Meknes International Festival for Animation Films in Morocco, and the newly established festival JoAnimate in Jordan. In contrast, the governments of Europe, Japan, and North America acknowledge the importance of the animation industry by giving financial support and arranging many animation festivals which develop the filmmakers and the animation industry in their countries.

Making animated feature films in the region is a massive risk due to the unstable market and the high expenses of making them. On the other hand, the Arab countries include more than 300 million people who speak the same language and share the same culture, and this would clearly be a promising marketplace if there were appropriate methods for media marketing to reach it. The Arab producers should take the Western animation markets as a model, and see how animation could have huge success and profits at the box office.

In 2009, Aljazeera News, one the biggest news broadcasting channels in the Middle East, had an interview with the animation producer and the cofounder of Ella Cartoon Studios, Mr. Osama Khalifa from Saudi Arabia. The title of this interview was *The reasons for the weaknesses of the Arab animation industry* (Without borders [Bila Hodoud] 2009). Khalifa produced more than 14 Arabic animated feature-length films; started with the feature animated film *The Island of the light* (1988) which was based on the Arabian novel *Hay Bin Yakzan* (*Living son of Awake*) which was written by the Andalusian philosopher and novelist Ibn Tufail in the early twelfth century.

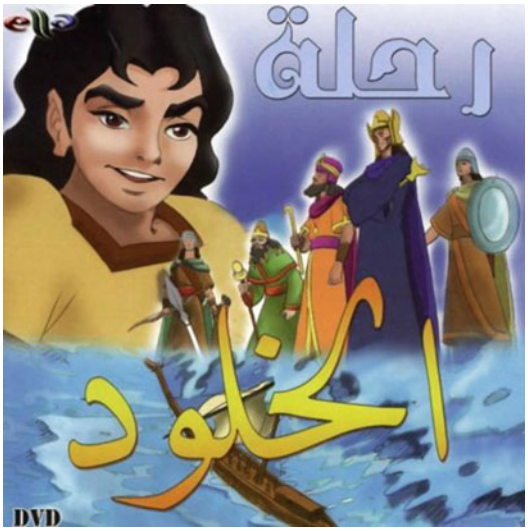
Most of Ella Cartoon Studios films are historical, such as *The Conqueror* (*Al Fatih,* 1995), a feature animated film that tells a story about the conquer of Constantinople in the fifteenth century by the Turkish leader Sultan Mehmed Al Fatih (Fig. 2). Also, the animated film *Conquered Andalucia* (*Fateh Al Andalous,* 1998), which tells a story about the Muslim hero Tariq Ben Ziad when he conquered Andalucia in Spain in the early eighth century to spread the religion of Islam in the West. The studio also made the



Challenges Facing the Arab Animation Cinema, Fig. 2 *The Conqueror* (1993) (Produced by Osama Khalifa)

feature animated film *The Lion of Ain Jalout* (*Asad Ain Jalout,* 1998) which tells a story about the Egyptian Muslim leader Prince Saif Al-din Qutuz when he led the Muslims to achieve victories against the Crusaders in Mansoura in Egypt and Mangouls in Ain Jalout in Palestine in the thirteenth century.

However, Khalifa also produced some religious animated feature films such as *The Immortal Journey* (*Rehlat Al-kholoud,* 1996) directed by Darwish Yasin (Fig. 3). The story is adapted from the Holy Quran, Surat Al-Buruj (The Mansions of the Stars) Chapter 85 verses 4–9. All of the animation and illustrations were made in cooperation with a studio in Turkey. However, the style of the illustrations and animation is similar to the Japanese cartoon visual style used in Anime and Manga, using common visual elements such as big eyes, minimum facial details, a lot of light and shade, and numerous camera rotations. Khalifa also produced a number of political animated films especially about the Palestinian Israeli conflicts, such as *The Olive's Dream* (*Holm Al Zaytoun*, 2009) and a 3D animated film *Martyr of World* (*Shaheed Al-alam*, 2003).



Challenges Facing the Arab Animation Cinema, Fig. 3 *The Immortal Journey* (1994) (directed by: Darwish Yasin, produced by Osama Khalifa)

None of the above films were supported by the Arab governments; they were made using their own money only. Khalifa indicates that the Arabic media market was empty of animation film productions and he decided to take a risk and make Arabic animated films for the Arab and international audiences. However, most of his animated films have been made using high quality overseas production in Turkey, Ukraine, and China due to the lack of Arab animation artists. Khalifa noted that the Arab animation industry produces less than 0.5 % of Western animation production. One year after the *Without Borders* interview, Ella Cartoon Studio went out of business, after 30 years of animation production.

Conclusion

Arab film producers made number of animated films by using a variety of stories such as religious, historical, political, and folk tales. In addition, the target audiences of most of his films are the general public and families. Nevertheless, they did not make enough profit for the studio to keep producing Arabic animated films. For this reason, his production company stopped making more films. The evidence suggests that there are a number of reasons for this struggle domestically and internationally, such as *cultural challenges*; the majority of the Arab people think that animation films are only for children and for that reason there is no success for theatrical releases of any Arabic animated films so far. However, Arab animation filmmakers are trying to convince investors and Arab audiences that the target audience of their animated films is general and refer to the huge success in animation in the West. Another reason could be *political challenges*; some of the films were made about the Palestinian Israeli conflict and those films could be difficult to screen in Europe and USA, because they might be considered as anti-Semitic. Moreover, most of Arab films have Muslim heroes who achieved victories against the Crusaders and Byzantine empires. The Arab film producers want to demonstrate the importance of making animated films appropriate to the Islamic religion and Muslim civilization. However, there is view that by making such historical stories, especially the conflicts between Muslims and Crusaders, would remind both Muslims and non-Muslims about the past, and it would "illustrate feelings, fears and animosities in the present" (Runneymede Trust 1997). Therefore, the target audience for any historical and religious films that show conflict with others might be limited to Muslim audiences only, and these types of animated films would be difficult to screen for an international audience due to subject matter that might offend the Western audience. This is the same as when Arabs and Muslims are offended by Western animated films that stereotype the image of Arabs and Islam in a negative manner.

Most of the Arab animated films were discussed so far are political, historical, and religious which could be one of the main reasons why those films are not reaching the international film marketplace. The previous examples show that the Arab animation industry is struggling in terms of budget, marketing, broadcasting, distribution, and government support. However, reaching the international market could be

achievable if Arab animation filmmakers and producers make universal stories that are suitable to everyone in the world. It is worth mentioning that a number of animated films from Arab countries found that the best way of making low-budget animated films/clips was to distribute them for free via the Internet and social media such as YouTube, Vimeo, Facebook, and other social media networks. The number of Arabic online videos increased greatly during and after the recent Arab revolution, the "Arab Spring" in 2011. This recent revolution gave Arab artists the freedom of expression to discuss whatever subjects they wanted to, including the political issues which attract a large number of audiences and received international channels' attention such as CNN, France 24, ABC News, Aljazeera, and other international channels, during the Arab Spring.

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Character - Avatar

▶ Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality

Character AI

▶ Character Artificial Intelligence

Character Animation Scripting Environment

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Synonyms

Animation scripting; Scripting environment; Scripting language

Definition

Scripting languages for character animation can be characterized as the earliest type of motion

control systems. In scripting environments, the required animations are generated by writing a script in the animation language. This means that a user must learn the animation scripting language. Such systems typically allow scenes and objects to be described, along with their relationship with each other. Among other advantages, they require no user interface and can therefore be implemented as cross-platform solutions.

Introduction

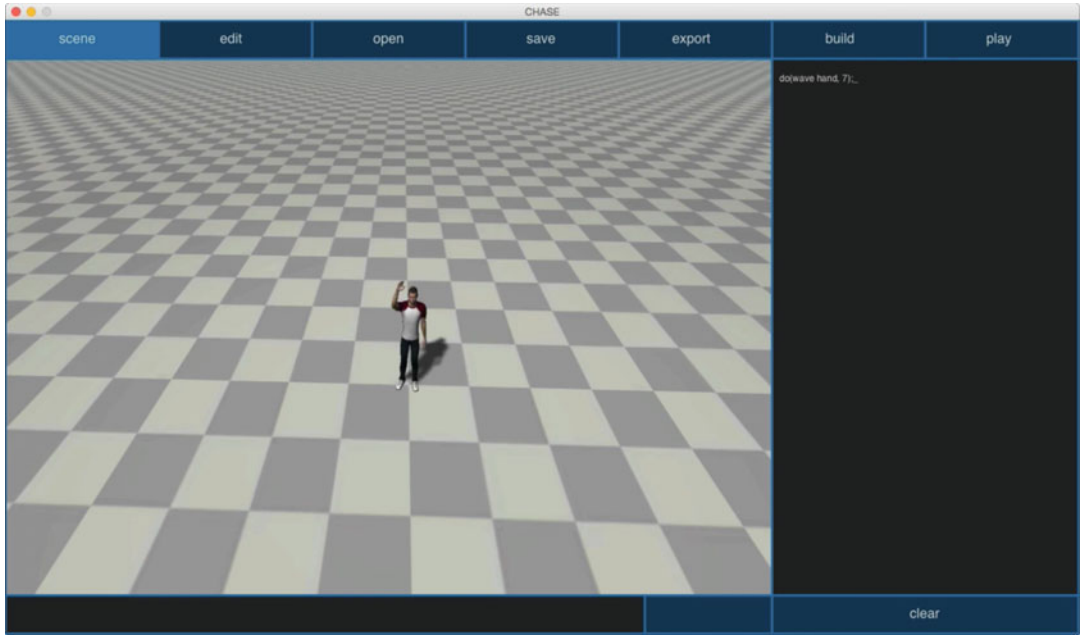
Character animation can be characterized as a complex and time-consuming process. This is especially true when animating virtual characters based on key-frame techniques, as this requires prior knowledge of software solutions. Moreover, artistic skills are also required since the virtual character should animate as naturally as possible.

In order to avoid time-consuming processes in animating virtual characters, motion capture technologies now provide high-quality and realistic animated sequences. This is possible because the ability to capture real humans in the act of performing is achieved through the provided required motions. The advantages of motion capture techniques are numerous, especially in the entertainment industry. However, the captured motion data, itself, is not always usable, since virtual characters should be able to perform tasks in which the required constraints are not always fulfilled. Thus, methodologies that retarget (Gleicher et al. 1998), wrap (Witkin et al. 1995), blend (Kovar et al. 2003; Park et al. 2002), splice (Van Basten and Egges 2012), interpolate (Kovar et al. 2002; Mukai and Kuriyama 2005), etc., the motion data have become available to help the animators to create the required motion sequences. In addition to the motion synthesis techniques that are based on software solutions, animating a virtual character through programming is also difficult. This is especially true in cases where animators, artists, and students do not have the required programming skills. Hence, animating virtual characters in order to visualize ideas and generate simple scenarios in which virtual characters evolve can be a very complex process.

Based on the aforementioned difficulties that inexperienced programmers can face, this paper introduces a simple, easy-to-use, scripting environment for animating virtual characters, which is based on a small number of scripting commands. The scripting environment presented (see Fig. 1), which is called CHASE, provides a user with the ability to script the action of a character as well as to script possible interaction between a character and objects that are located within the virtual environment.

In order to implement CHASE, the following parts were developed. Firstly, identify the basic actions that a character should be able to perform and also generate the basic scripting commands. Secondly, a number of parameters that should allow the user not only to synthesize the required motion of a character but also to gain a higher level of control of each action of the character were defined. By using a reach number of motions that a character can perform, as well as by associating these actions with specified keywords, a motion dataset is created. The input commands are handled by a number of developed background algorithms, which are responsible for retrieving the desired motions and synthesizing the requested actions of the character. During the application's runtime, CHASE synthesizes the requested motion of the character and displays the final animated sequence.

The remainder of this paper is organized as follows. The section "Related Work" covers related work in character animation by presenting previous solutions for animating virtual characters that are based on interactive or automatic techniques. Previously developed scripting environments for the animation of virtual characters are also presented and discussed. A system overview of CHASE is presented in section "System Overview." The script commands, possible parameters, and additional functionalities that have been developed for CHASE are presented in section "Scripting Character Animation." Finally, conclusions are drawn and potential future work is discussed in section "Conclusions and Future Work."



Character Animation Scripting Environment, Fig. 1 The interface of CHASE

Related Work

This section presents work that is related to the solution presented. Specifically, the following paragraphs present methodologies that use different input devices or easily specified constraints for animating virtual characters, systems that provides to a user the ability to synthesize task-based or scenario-related animated sequences, and previously proposed scripting environments for character animation. Finally, the advantages provided by CHASE comparing by previous solutions are presented.

Interactive character control can be classified according to the input device that is used for the character animation process (Sarris and Strintzis 2003). In general, the character controller can be a standard input device, such as a keyboard and a joystick (McCann et al. 2007). Alternatively, it can be more specialized, such as text input (Oshita 2010), prosodic features of speech (Levine et al. 2009), drag and drop systems where the motion sequences are placed into a time-line (Oshita 2008), sketch-based interfaces (Davis et al. 2003), or the body of a user (Chai and Hodgins 2005), while the motion is captured by motion capture technologies. Each of the previously mentioned methodologies has advantages and disadvantages. The choice of the most appropriate input device depends on the actual control of the character's motion that the user requires.

A variety of methodologies for the animation of a virtual character based on easily specified constraints have also been examined. These solutions are based on motion graphs (Kovar et al. 2002); literature such as Safonova and Hodgins (2007); simple footprints (Van De Panne 1997) that a character should follow, on space-time constraints as proposed in Cohen (1992); or statistical models (Min et al. 2012) that are responsible for retrieving and synthesizing a character's motion. However, even if easily specified constraints enable a user to animate a character, different frameworks that permit either the interactive or automatic animation of a character have been developed. In Feng et al. (2012), which is a task-based character animation system, by using a number of screen buttons, the user is able to animate a character and make it interact with objects that are located within the virtual

environment. Other methods (Thiebaux et al. 2008; Kapadia et al. 2011; Shoulson et al. 2013), which can be characterized as scenario-based character animation systems, provide automatic synthesizing of a character's motion based on AI techniques.

In the past, researchers developed scripting languages and systems in the field of embodied conversational agents. The XSAMPL3D (Vitzthum et al. 2012), AniLan (Formella et al. 1996), AnimalScript (Rößling and Freisleben 2001), SMIL-Agent (Balci et al. 2007), and many others enable a user to script a character's actions based only on predefined command. Among the best known markup languages for scripting the animation of virtual characters are the Multimodal Presentation Markup Language (Prendinger et al. 2004), the Character Markup Language (Arafa et al. 2003), the Multimodal Utterance Representation Markup Language (Kranstedt et al. 2002), the Avatar Markup Language (Kshirsagar et al. 2002), the Rich Representation Language (Piwek et al. 2002), the Behavior Markup Language (Vilhjalmsson et al. 2007), and the Player Markup Language (Jung et al. 2008), which were developed for controlling the behavior of virtual characters.

The representation of all previously mentioned languages is based to an XML-style format that allows users to script tasks featuring virtual characters. However, these languages focus more on communicative behavior such as gestures, facial expression, gaze, and speech of virtual reality characters, instead of providing functional characters that can generate scenario-related animated sequences.

Various solutions that are similar to the presented methodology were proposed previously for the animation of virtual characters based on scripting commands. StoryBoard (Gervautz et al. 1994) provides the ability to integrate a scripting language into an interactive character animation framework. Improv (Perlin et al. 1996), another framework with which to create real-time behavior-based animated actors, enables a user to script the specific action of a character based on simple behavior commands. STEP (Huang et al. 2002) framework provides a user the ability to script such actions as gestures and postures. This methodology, which is based on the formal semantics of dynamic logic, provides a solid semantic foundation that enriches the number of actions that a character can perform.

The majority of previously developed scripting environments and markup languages provide only specific actions that a character can perform. An additional limitation is the inability of such systems to enhance a character's synthesized motion. Therefore, a user always receives a lower level of control of the synthesized motion of a character. Moreover, in cases in which a user must generate an animated sequence where many characters will take part, a great deal of effort will be required due to the difficulty of scripting multiple actions for multiple characters. This is especially true for users who wish to generate a sequence with animated characters, but are inexperienced in programming.

These difficulties are overcome in the presented scripting environment. Firstly, instead of enabling a user to script an animated character based on XML-related formats, a simplified scripting environment with its associated scripted language, which is based only on three commands, is introduced. Secondly, since a character should be able to perform concurrent actions, a simple extension of the basic command handles this. Therefore, the user achieves a higher level of control of a character's action. Moreover, in cases where a user must animate more than one character simultaneously, one can specify the character that should perform the requested action by adding an additional method to the existing command for a character. Finally, in cases where a user must generate an animated character in a multitask scenario, by simply specifying the row in which the task should appear, the system will synthesize the tasks requested automatically.

We assume that the described unique functionalities that are implemented in CHASE will enable a user to synthesize compelling animated sequences in which a variety of virtual characters are involved. Hence, in view of the simplicity of the developed commands, in conjunction with the associated parameters, the proposed methodology is quite powerful in comparison with the previous solution. In addition, the easy-to-use and easy-to-

remember commands make the presented scripting environment effective, especially for users who are inexperienced in programming.

System Overview

This section briefly describes the proposed system. Specifically, a variety of background algorithms are responsible for recognizing the input commands and synthesizing the motion of a character. The developed background algorithms communicate with the animation system, which is responsible for generating a character's motion, as well as with a path-finding methodology to retrieve the path that the character should follow when a locomotion sequence is required. Finally, CHASE synthesizes and displays the requested motion sequence. Figure 2 represents the procedure.

Interface

The interface of CHASE (see Fig. 1) is characterized by its simplicity. In its current implementation, it consists of a scene panel that displays the resulting animations, an edit mode panel to edit the input objects, a progress bar that shows the progress of the displayed animation, a scripting box, and a few buttons for use in building, playing, and clearing the written scripts. Finally, buttons that save the scripted code and export the generated animated sequences are also provided.

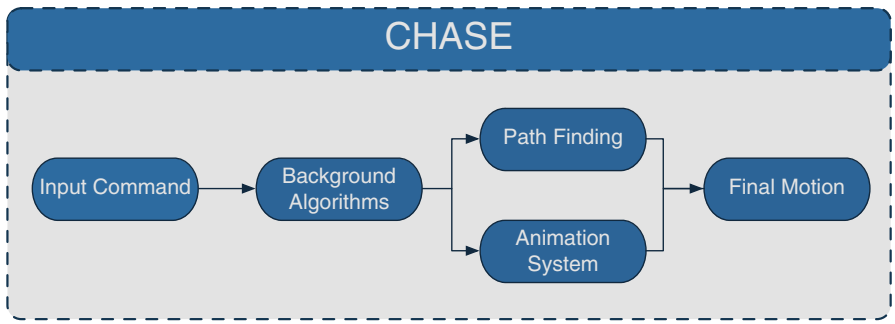
A downloadable version of the presented system, documentation specifying all of its capabilities, and examples of scenes can be found on the CHASE project page.

Third-Party Implementations

A number of techniques and libraries are used to construct CHASE. CHASE uses the Recast/Detour library (Mononen 2014) for the path-finding process and collision avoidance with the environment. Concurrent actions are generated based on a simple layering methodology similar to the one proposed in Oshita (2008). Finally, a similar (Lang 2014) full-body inverse kinematics solver was implemented to handle the postures of a character while interacting with objects located within the virtual environment.

Scripting Character Animation

Developing scripting commands for animating a virtual character can be characterized as a complex process since a virtual character should be able to perform variety of actions. In this section, the identifications of the basic scripting commands that are necessary to enable the virtual character to navigate and interact within a virtual environment are presented. Moreover, by introducing additional methods called by the main scripts, the system generates concurrent actions of a character, as well as animates multiple characters simultaneously. Finally, an additional functionality of CHASE for scripting multitask animated sequences for the generation of scenario-related animated characters is presented.



Character Animation Scripting Environment, Fig. 2 The architecture of CHASE

Identifying Scripting Commands

The application that is presented has been developed for users who are inexperienced in programming. Thus, simple, easily memorized scripting commands are necessary. To generate the required scripting commands, one must begin by identifying the possible actions or type of actions that a character should perform. Generally, a character should be able to perform simple actions such as waving its hand, tasks related to locomotion such as moving to a target position, and interaction tasks such as grasping with its hand an object that is located in the three-dimensional environment. It is apparent that these are the three basic types of actions that a virtual character should be able to perform. Based on this general description, three basic scripting commands were developed: the do(parameters), the goTo(parameters), and the interactWith(parameters).

The do(parameters) command provides a character with the ability to perform a single action. The goTo(parameters) forces a character to move within the given virtual environment. The final command is responsible for making the virtual character capable of interacting with a variety of tasks. Hence, the third command, the interactWith (parameters), is responsible for providing the ability to control a variety of the character's actions.

For these commands, the parameters within the parentheses indicate the possible parameters that each of the scripting commands could receive (see section Command Parameters). Due to the various parameters that each command receives, a user is provided with the means to develop both abstract and specified action of a character. For example, with the goTo(parameters) command, it is possible not only to generate the required locomotion of a character but also to enable a user to gain better control of the synthesized motion of a character, since the user can specify how the locomotion of a character should be generated. The following section presents the basic parameters that each command receives.

Command Parameters

A task assigned to a character can be performed in a variety of different ways. For example, a sequence of locomotion to a target position can be performed by walking, running, etc. motions. Hence, in cases where a user needs a higher level of control of the synthesized motions of a character, parameters that enhance these actual actions generated by the previously mentioned scripting commands should be defined.

The first command that implemented the do (parameters) command enables a user to script simple actions of a character. This command has a single mandatory parameter, which indicates the action that the character should perform. However, optional parameters to specify the body part or the duration of the task can also be used. Specifically, the user can request a single action by calling do(action), as well as specify the target where the action should be performed, the duration of the action, and the body part that should perform the requested action. This command initially permitted a character to perform the requested action without the need to perform a locomotion sequence (i.e., to wave its hand while staying in its position). However, the do(parameters) command can also be used to permit the character to perform locomotion tasks, since one can request that a character performs a walking motion. Based on these parameters that can be inserted into the do (parameters) command, a user has the means not only to generate the requested action but also to generate an action that should fulfill user-specified constraints.

The goTo(parameters) command enables the character to perform locomotion tasks. The user identifies a mandatory parameter, which is the target position that the character should reach. However, the user is also able to use an additional optional parameter that specifies the motion style that will animate the character. Therefore, a character's locomotion to a target position can be scripted either by (i) inserting the target position such as goTo(target) when a simple walking motion of the character is desired or (ii) inserting goTo(target, motion style) when both target position and motion style are specified.

The final command that is implemented in CHASE, the interactWith(parameters), can be characterized as more complex than the two previously mentioned commands. The reason is that

there are numerous possible interactions between a character and an object. If a character is asked to interact with an object, various actions can be generated. Even if it is possible to associate actions with specific body parts of a character in a preprocessing stage, there are also possible variations of the required actions. These variations may be related to the character's body or to the duration of the display of the action. For example, scripting a character to kick a ball may also require specifying the foot that should perform this action. Moreover, asking a character to knock a door may also require specifying the duration in the knocking. For that reason, four different parameters have been defined. The first two parameters (object name and interaction module) are mandatory. They indicate the object that the character should interact with and the interaction module that should be generated. However, depending on the user's requirements for generating a specific action, two more optional parameters could also be inserted. The first one (body part) enables the user to choose which of the character's body parts should perform the requested action. In the current implementation, the user is permitted to choose the hand or foot that will perform the action. The second parameter (duration) enables the user to choose the time (in seconds) required for the requested action.

Based on the possible parameters that each command could receive, the following should be noted. Firstly, while the user did not specify any optional parameter for a scripted command, the system generates the required action taking into account a predefined set of parameters that are associated with each action of the character. For example, if a user requests that a character kick a ball, the system will display only a single kick by the character. The reason is that a ball kicking action is defined as to be performed only once to avoid synthesizing meaningless and repeated motions. Secondly, it should be noted that each optional parameter is independent. This means that the user is not required to specify all of the optional parameters provided by each command. Therefore, the user may control specific components of the requested action.

A simple example of this capability of the commands illustrates this. While using the do (parameters) command, the user may request that only either the body part or the duration parameter or both of these be filled. In any case, the system's decision in generating the requested motion is not influenced by other factors since it is capable of recognizing the correct form of the scripted command in all of the aforementioned cases.

The three commands that are examined in this paper in conjunction with the associated parameters that can be used to animate a virtual character are summarized in Table 1. In addition, a small set of possible keywords that the user could employ in order to animate virtual characters is presented. It is assumed that an additional control parameter for the synthesized motion could be quite beneficial, since it enables the user not only to animate a character but also to force the system to synthesize the user's actual wish. Complete documentation of all possible actions that can be synthesized by the character can be found in the CHASE webpage (*URL omitted for review purposes*).

Scripting Concurrent Actions

Virtual characters, such as humans, should be able to perform more than one action simultaneously. This section presents the scripting process for concurrent actions that a character can perform. The concurrent action functionality is based upon the ability to specify the body part that should perform the action in conjunction with the base action that has been requested. The concurrent action lies between the do(parameters) and either the goTo(parameters) or the interactWith(parameters) commands. Specifically, to have a character perform concurrent actions, the do(parameters) command is attached to either the goTo(parameters) or the interactWith (parameters). A simple example follows. To cause a character to perform a motion, such as waving its hand while walking to a target position, the system permits the user to script the desired walking motion of a character and to request the additional motion that the system should generate. Hence, the previous example can be requested simply by scripting goTo(target, walk).do(wave hand, handR). Thus, by permitting the user to generate additional actions of a

Character Animation Scripting Environment, Table 1 Commands and associated parameters that can be used in CHASE to request an action by an animated virtual character

Commands	Parameters	Parameter examples
do(parameters);		
do(action);	Action	Wave hand
dofaction, target);		Jump
dofaction, duration);		Walk
dofaction, body part, target);		Kick
dofaction, body part, duration);		Etc.
	Target	Vector3 (x,y,z) object name
	Duration	Time in seconds
	Body part	HandR
		HandL
		FootR
		FootL
		UpperB
		LowerB
goTo(parameters);		
goTo(target);	Target	Vector3 (x,y,z)
goTo(target, motion style);		Object name
	Motion style	Walk
		Run
		Jump
		Walk back
		Etc.
interactWith(parameters);		
interactWith(object name, interaction module);	Object name	Any object's name contained in the scene
interactWith(object name, interaction module, body part);		
interactWith(object name, interaction module, duration);		
interactWith(object name, interaction module, body part, duration);		
	Interaction module	Kick
		Punch
		Grasp
		Sit
		Open
		Close
		Etc.
	Body part	HandR
		HandL
		FootR
		FootL
	Duration	Time in seconds

character, while another action is in progress can, be quite beneficial when more complex animated sequences are required. Therefore, this additional functionality provides a higher level of control over a requested action of a virtual character.

Scripting Multiple Characters

In animated sequences, it is quite common for more than one character to participate in a single scenario. Hence, by extending the three scripting commands, CHASE also enables a user to script

more than one character simultaneously. This is achieved by attaching an additional command to one of the three basic commands, called characterName(parameter). This command specifies the character that should perform an action, permitting the user to control multiple characters, in cases where more than one character participates in the animation process. A simple example of forcing a specific character to perform an action follows. Consider a character named Rudy who is required to walk to target. This procedure could be called by simply scripting goTo(target). characterName(Rudy).

Scripting Multiple Tasks

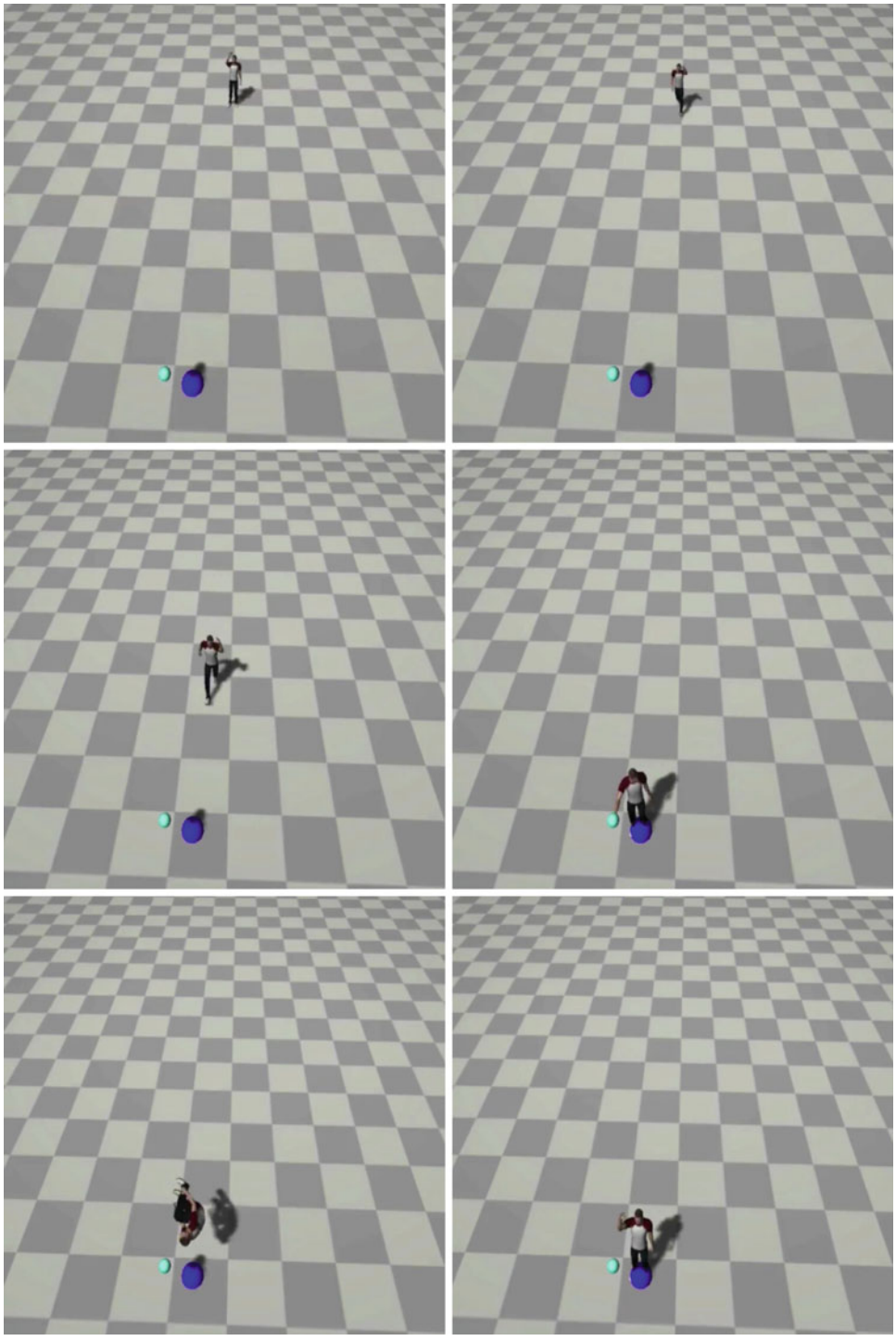
In scenario-related sequences that involve virtual characters, the latter should be able to perform a variety of tasks one after the other. Thus, this paper presents a method to script multiple tasks, such as enabling a user to synthesize long animated sequences. Generally, the tasks that a character can perform are characterized by their linearity. Specifically, a task begins while a previous task is completed, and the procedure continues until there are no other tasks for a character to perform.

Based on the foregoing, a multitask scenario in a general form can be represented as components of an array that has a dimensionality equal to $N \times 1$, where N denotes the total number of tasks that a character should perform. By assigning each of the actions an array called task[index], a user can generate long animated sequences. This is achieved by allowing the user to assign singe tasks at each index value of the task array. A simple example of a multitask scenario appears in Fig. 3, as well as in the accompanying video. Its scripting implementation is represented in Algorithm 1.

It is quite common in multitask scenarios to involve multiple characters. Two different approaches can be used in CHASE to script more than one character simultaneously in a multitask scenario. The first approach animates each character one after the other. This means that the action required of a characterB is generated after the action of a characterA has been completed. The reason is that each task of the characters taking part in the multitask scenario have been assigned a different index value of the task array. A simple example of generating the actions of two different characters appears in Algorithm 2. However, a user should be able to animate virtual characters simultaneously in multitask scenarios. This is achieved in CHASE by using a two-dimensional array named tasks[index][index]. In this array the first index value represents the row in which each action in generated, whereas the second index value represents the number of the character. It should be noted that each character should be represented by the same index value while developing a multitask scenario. Hence, the background algorithms that are implemented recognize and generate the requested tasks as separate entries. This enables the user to animate a number of characters simultaneously. A simple example in which there are two characters in a multitask scenario appears in Algorithm 3. It should be noted that a multitask scenario where multiple characters evolve in a general form can be represented as an array that has a dimensionality equal to $M \times$ N, where M denotes the total number of characters evolving in the multitask scenario and N denotes the total number of tasks that a character should perform.

Conclusions and Future Work

In this paper, a novel scripting environment, called CHASE, for use in animating virtual characters was presented. CHASE enables a user to request a variety of actions that a character can perform by simply using three commands. Each command, which receives a variety of parameters, is associated with specific actions that the character is able to perform. Moreover, the commands communicate with a variety of background algorithms that are responsible for generating the actions requested of the character. In addition to the scripting commands, by introducing three additional functionalities, the user is able to script concurrent actions of a character, multiple characters at the same time, and multitask scenarios in order to generate scenario-related sequences that involve animated characters.



Character Animation Scripting Environment, Fig. 3 A multitask scenario generated by using Algorithm 1

Character Animation Scripting Environment, Algorithm 1 A simple example for generating a multitask scenario

Data: input commands of a user
Result: the result animated sequence
task[1] = do(wave hand, handR, 3);
task[2] = goTo(ball, walk).do(wave hand, handL);
task[3] = interactWith(ball, punch, handR);
task[4] = do(jump);
task[5] = do(wave hand, handR, 2);

Character Animation Scripting Environment, Algorithm 2 By placing the actions of two different characters at different index values of the task array, the system generates each character action one after the other

Data: input commands of a user
Result: the result animated sequence
task[1] = goTo(ball, walk).characterName(characterA);
task[2] = goTo(ball, walk).characterName(characterB);

Character Animation Scripting Environment, Algorithm 3 A multitask scenario in which there are two characters. In this scenario, characterA moves to its target position while walking, and characterB moves to its target position while running. Finally, characterA punches characterB with his right hand

Data: input commands of a user
Result: the result animated sequence
tasks[1][1] = goTo(target, walk).characterName (characterA);
tasks[1][2] = goTo(target, run). characterName (characterB);
tasks[2][1] = interactWith(characterB, punch, handR). characterName(characterA);

Cross-References

▶ Teaching Computer Graphics by Application

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C

Character Artificial Intelligence

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Synonyms

Character AI; Decision-making; Perception AI

Definition

A character AI is a system that makes decisions for what a character will do. Here, a decision means a strategy, tactics, or a certain behavior. Character AI does not only refer to the decision-making process, but also to the whole system used for dynamically connecting the character's AI and the game world. Such systems implement what is called as an "agent architecture" (Russell and Norvig 2016a). An agent architecture of character AI has three modules: perception, decision-making, and memory modules.

Introduction

In this entry, an overview on the history of the development of character AI is presented. Characters' AI techniques differ depending on the scale of the game. For small-size games, "scripted AI" is the most used method for controlling a character, whereby a scripted AI system uses script languages to issue commands that directly determine characters behaviors. For middle-size games, decision-making algorithms, such as rule-based systems, state machines, or behavior trees, are used. For large-size games, character AI is controlled by a large system based on an agent architecture with a perception module, a decision-making module, a motion-synthesis module, a memory module, and so on.

Drastic changes in character AI technologies came from the first 3D games made in the 1990s. In 3D games, characters must have their own artificial intelligence. Each character must have sensors and a body of its own and perform decision-making thinking. Characters with these traits are called "autonomous agents." From the late 1990s to 2010, the focus of character agent research shifted from scripted agents to autonomous agents (Miyake et al. 2017).

In the second half of the 1990s, research for character AI began at the MIT (Massachusetts Institute of Technology), and many robotics technologies have been applied for character AI in the game industry ever since. The MIT synthetic character group (MIT Synthetic Character Group 2003) has studied AI for virtual creatures. They introduced AI techniques from the field of robotics to autonomous agents in digital games. One agent architecture that they developed using a blackboard architecture is called the "C4 architecture" and is shown in Fig. 1 (Isla et al. 2001; Burke et al. 2001). The main feature of this model is to separate intelligence modules and memory modules. Their research results were presented in GDC 2001, and it had a profound impact in the game industry. For example, Halo 2 and F.E.A.R. (2005, Monolith Productions) used this architecture (Orkin 2005, 2006).

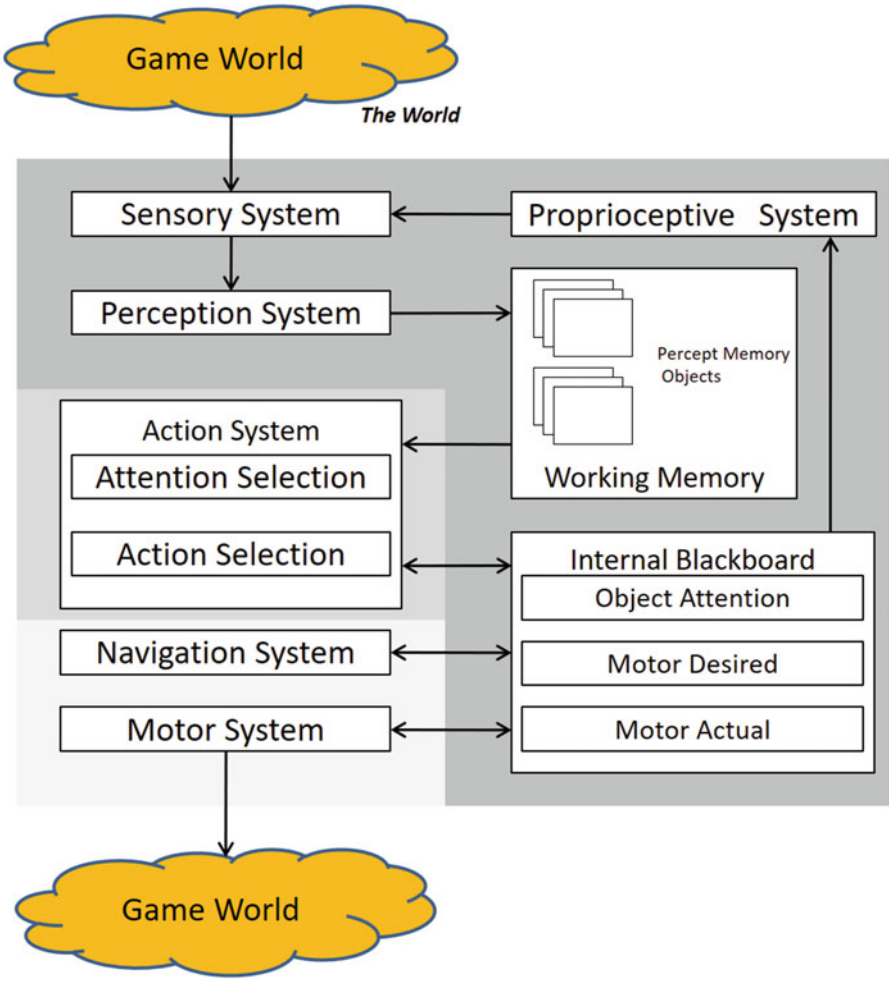
Similar to a C4 agent architecture, generally an agent architecture for a game character consists of several software modules, such as a sensor module, a recognition module, a decision-making module, a motion-making module, and an effector module. A system that employs a sensor module and a recognition module is called a "perception AI" system, which is used for recognizing the environment in the game (see section "Perception AI"). The decision-making module is the largest module and is used for making decisions using certain decision-making algorithms, such as rule-based, state-based, behavior-based, utility-based, goal-based, task-based, and simulation-based decision-making algorithms (Miyake 2017) (see sections "Decision Making for Game Characters" and "Memory and Knowledge Representation").

Perception AI

A character in a digital game must recognize the environment around itself in real time to respond to changes in the world. However, it is impossible for a character AI to recognize the game world directly, because it would be an excessively heavy load for an AI agent to analyze and understand the environment around itself from its point of view in real time. Perception AI systems are used to help character AIs to recognize the environment in the game.

The role of perception AI is to acquire information of the environment via physical simulations, such as ray-casting and sound propagation, and to abstract an essential whole-world image from this information. Perception AI essentially means how the game world is seen from the point of view of a character.

Perception AI uses efficient methods to acquire information of objectives and terrain from a game stage. All objectives contain information that they use to represent themselves. For example, a rock in a game would have properties such as "rock," "breakable," and "movable," and a door in a game would have properties such as "door," "open," and "can go through," and so on. In Halo 2, the battlefield of the game is divided into three parts, namely the front area, the middle area, and the back area. A representation of objectives is called a knowledge representation (KR), and a

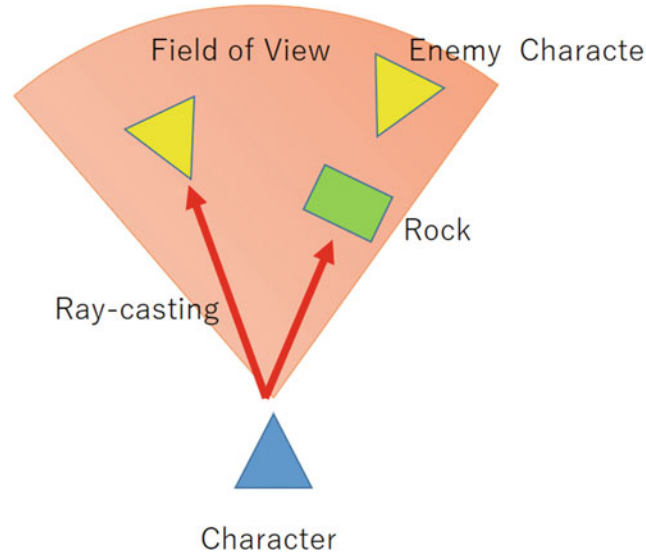


Character Artificial Intelligence, Fig. 1 C4 architecture (Isla et al. 2001; Burke et al. 2001)

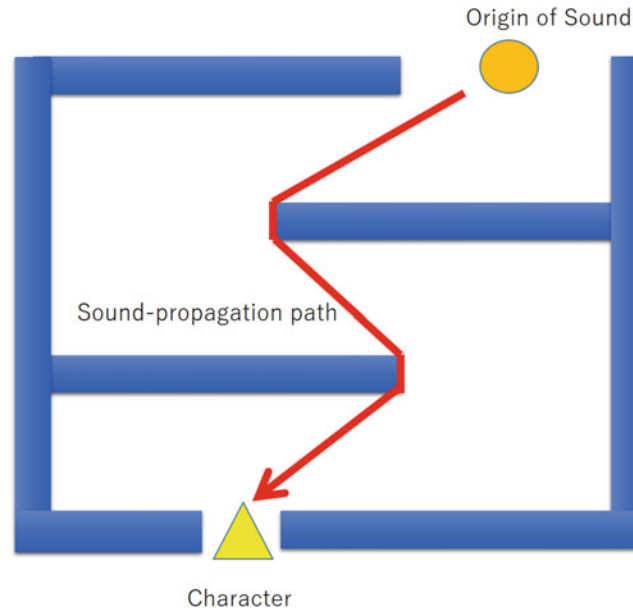
representation especially for terrain and space is called a world representation (WR). By using KR and WR information, a character can recognize its present situation.

Perception AI involves sensor modules for performing specific simulations and may include five modes for representing the five human senses. Visual sensors are the most important in digital games because the human player's actions also depend on the player's sight. In general, the visual sensors of a character have visual regions called "field of vision," as shown in Fig. 2. When an object enters the field of vision, one or multiple rays are casted onto the object. If the ray can go through and reach the object without any collision with other objects, it means that the character can see the object. This is the principle behind visual sensors.

In stealth-based games in particular, perception AI is very important. Stealth-based games are games in which the player generally breaks into a building while hiding from enemies. All enemies have vivid perception AI. For example, in Splinter Cell: Conviction (Ubisoft 2010), each enemy has a field of view in the shape of a coffin because this shape is very useful for being able to see the deepest and farthest region of narrow rooms. In Final Fantasy XV (SQUARE ENIX



Character Artificial Intelligence, Fig. 2 Vision sensor with a field of view



Character Artificial Intelligence, Fig. 3 Sound propagation

2016), each character has two visual regions consisting of a forward circular sector and a backward circular sector. The forward circular sector can recognize objects clearly, whereas the backward circular sector has ambiguous recognition functions for vaguely noticing objects.

To implement hearing, the easiest way involves the use of a spherical sound source with a certain radius around a character. This sphere is used to determine if a character can hear the sound coming from the origin. Furthermore, in some stealth-based games, as shown in Fig. 3, sound-propagation simulations are performed to confirm the existence of a sound path through space from the origin to a character by connecting the edges of walls. Moreover, in Sprinter Cell: Blacklist, sound propagation was implemented. The shortest path for sounds is calculated by connecting the edges of walls (Walsh 2014). In Hitman (Io-Interactive 2016), sound propagation

is calculated via diffraction and transparency (Rørbech 2015).

And typical collision or overlapping sensors are used for character's touching to objects.

Decision-Making for Game Characters

The decision-making algorithms used in digital games can be classified in seven types, namely rule-based, state-based, behavior-based, task-based, goal-based, utility-based, and simulation-based algorithms (Fig. 4).

In the 1980s, almost all games used rule-based algorithms to control characters, as in, if the player's position is to the right, then go left. Some rules were prepared, and one rule was selected to be executed after evaluating all rules. Even now, rule-based algorithms are very popular for small- and middle-size (sometimes even big-size) games. For example, The Sims 3 (Maxis 2009) uses rule-based methods to control NPCs (nonplayer characters) by preparing and executing multiple action rules (Evans 2010).

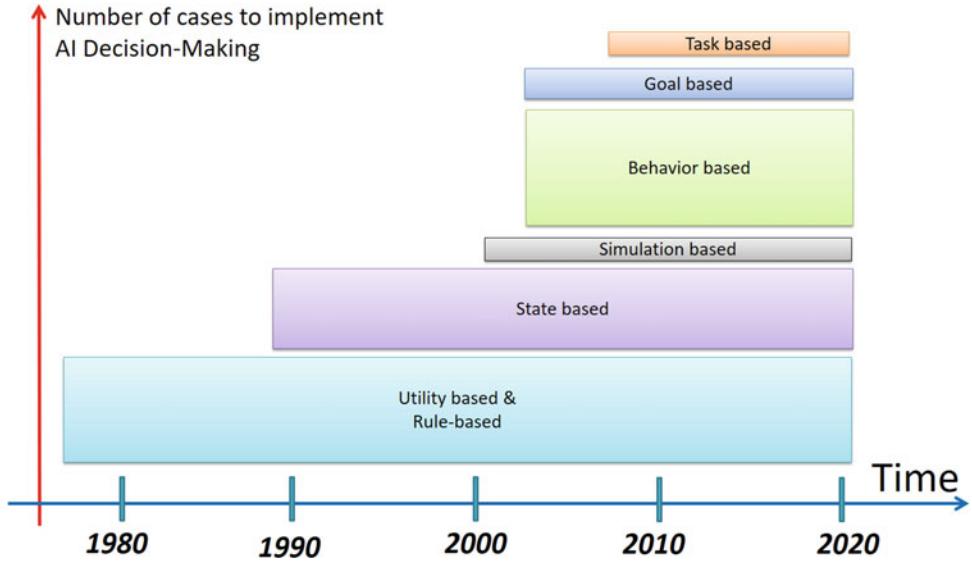
In the 1990s, especially in the first 3D games, state-machine methods became popular. State-machine methods are suitable for describing a character's behavior and its transitions in 3D space. Many game developers made original state-machine GUI tools, and some middlewares were supported by AI middleware companies. For example, character AI in Uncharted 2: Among Thieves (Naughty Dog, LLC, 2009) is based on a state-machine system (Gregory 2009) (Fig. 5).

Utility-based algorithms represent a method for selecting one option from many by calculating their value. For example, a character may have many actions that they could execute in a given situation. The character's AI selects one action out of all possible actions by calculating their corresponding utility value. Utility can alternately mean "effectiveness" or "evaluation value."

Behavior-based algorithms began to be used for character AI in Halo 2 in 2004 (Isla 2005a, b). In Halo 2, a new method called "behavior tree" was developed for character AI by Damian Isla, the AI lead of the game. A behavior tree is a hierarchical acyclic directed tree that originates from a root and reaches behaviors, as shown in Fig. 6 An advantage of behavior trees is their scalability, by which users can modify a behavior tree without having to perform complex

Decision Making Algorithm	Features	Game titles
Rule-based	Rules are listed, and one of them is selected.	The Sims 4 (Maxis, 2014), etc. All classic games
State-based	States are connected by transition conditions.	Uncharted 2 (Naughty Dog, 2009), etc.
Behavior-based	Behavior tree	Halo2 (Bungie, 2004), etc. Many modern games
Utility-based	Evaluating choices	The Sims (Maxis, 2000), etc. Many classic games
Goal-based	Goal first. A goal is decided, and how to achieve is considered.	F.E.A.R. (Monolith, 2005) Chrome Hounds (FROM SOFTWARE, 2006)
Task-based	Hierarchical Task Network	Killzone 2,3 (Guerrilla Games, 2009, 2011)
Simulation-based	Simulating a character behavior in a space	Racing games, robotic games, etc.

Character Artificial Intelligence, Fig. 4 Comparison of seven decision-making algorithms



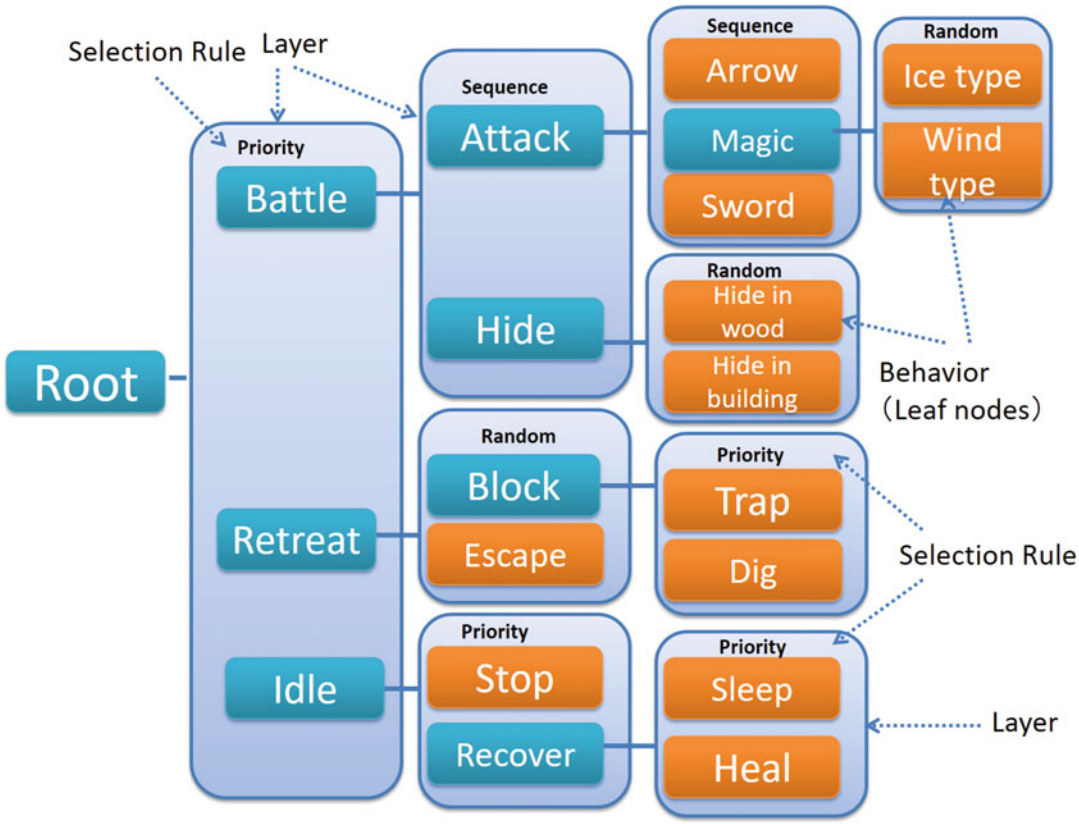
Character Artificial Intelligence, Fig. 5 Time table of decision-making algorithms

operations. When one state is added to a state machine, all the connections between the new state and old states must be considered. However, when one node is added to a behavior tree, only the local structure around the new node has to be considered. Behavior trees have become the most popular algorithms in the game industry. In more than 70% of big-size and mobile games, at least one behavior tree is used.

Behavior trees have a layered architecture. Each layer of a behavior tree has several child nodes and one selection rule. Each layer selects nodes to be executed via the selection rule. First, for each behavior, the tree judges whether it is possible to execute that behavior or not under the current situation, and the nodes that are deemed unfeasible to become active are removed from the selection process. Then, nodes are selected based on rules applied to the remaining ones. Based on the selection rules, the selection process unfolds. For example, a layer with a "sequence rule" executes its nodes in a certain order according to priority. On the other hand, layers with a "priority rule" attempt to execute only one node with maximum priority out of all the nodes that could become active. Layers that employ a "random rule" execute one node selected at random.

Goal-based algorithms began to be used in 2004. For example, F.E.A.R. uses goal-oriented action planning (GOAP). GOAP is a kind of STRIPS (Stanford Research Institute Problem Solver) developed in the 1970s. Usually, this solver is used for making long static plans. However, Jeff Orkin applied STRIPS to the real-time planning of characters' actions by chaining many actions, which are described by a precondition, an action, and a postcondition, to produce a long actions plan (Orkin 2005, 2006).

Task-based algorithms are the most promising for the future of game AI because they can be used to develop the most complex thinking patterns for character AIs. Hierarchical task networks (HTNs) are decision-making algorithms for making plans similarly to node networks. They were developed in academic research in the 1990s (Russell and Norvig 2016b). HTNs have domains and methods. A domain means a collection of tasks, which represents a region of a problem. Methods divide one task into smaller tasks in a domain. HTNs have hierarchical methods and domains. A task which can be resolved into subtasks further by its method is called a composite task, and a task



Character Artificial Intelligence, Fig. 6 Behavior tree

which cannot be resolved further is called a primitive task. Killzone 2 and 3 (Guerrilla games, 2009, 2011) used HTNs (Straatman et al. 2009, 2013; Champandard 2008), and a few other companies used them.

Simulation-based algorithms are used for solving complex problems that cannot be transformed into more easily solvable problem. In such cases, simulation-based methods are very effective. For example, when an AI car goes through a narrow cave, it tests some combinations of turns and accelerations to find the best combination for moving smoothly.

Although there are seven types of decision-making algorithms, only one or two algorithms are used in each game. The design of decision-making systems and tools is done by engineers, whereas implementing decision-making thinking using those tools is done by the game designer. For example, there are many different behavior tree tools made by different game companies, and many game engines contain proper decision-making tools.

Memory and Knowledge Representation

A character's AI stores information on its memory. The information stored in this memory can have many knowledge types, which are referred to as knowledge representations (KRs), as explained in the section "Perception AI." Any knowledge has a form of KR.

For game characters, it is difficult to recognize terrains, objects, or facts in the game by themselves. Knowledge representations of all the things that a character must recognize are prepared during game development so that characters can recognize the game world via KRs.

A character's memory is basically a collection of variables. However, in highly developed AIs, memory must be formatted via KRs.

For example, in Halo 2, some objects have "affordance" information (Isla 2005b). Affordance is a concept that indicates possible activity. It is a term used in cognitive psychology for concepts such as eatable, movable, breakable, and so on. If the KR of an object is "movable," the character recognizes that the object can be moved by referring the object's KR.

In F.E.A.R., the KR of characters is more sophisticated and is called a World Memory Fact (WMF). A WMF has a unified data structure (Orkin 2005):

```
WorkingMemoryFact
{
Attribute<Vector3D> Position
Attribute<Vector3D> Direction
Attribute<StimulusType> Stimulus
Attribute<Handle> Object
Attribute<float> Desire
 ...
 float fUpdateTime
}

Attribute<Type>
{
 Type Value
 float fConfidence
}
```

(This is C++ code to define the WMF data type. Each piece of information has a confidence value.)

Another notable example is Gunslinger (2002, not released, Surreal). The title was not released, but it exerted much influence in the KR implementations of subsequent games. This title also had KR for facts in the game. The KR of an event had components, such as Subject Group, Verb, Object Group, Object Individual, Magnitude, Where, When, and Template (Alt and King 2002). First, any event that was seen by a character was registered in the global memory with an ID. The characters who saw the event had a reference to the event's ID. For example, assume that Joe was killed by the lawmen in the square at noon. This fact is remembered by an event manager, and each witness of that fact has a reference to the event stored in the event manager. Each event has a reference counter that indicates the number of witnesses who remember the fact. When a witness is killed, the reference counter is reduced.

Conclusion

Character AI represents one of the cores of a digital game's AI. Many AI and robotics technologies are integrated in character AI technology. During the early stages of character AI development, many robotics technologies were employed. However, the speed of the technical progress of character AI has been very fast, such that AI technologies originally taken from robotics have been developed in the game industry more than in the robotics industry. In the near future, character AI techniques developed in the game industry will be used in fields involving digital characters other than gaming. Further into the future, more learning or evolution systems will be introduced and partially replace these decision-making systems.

The reason for this is that character AI can be simulated in a game world without involving real bodies and avoiding physical troubles. Thus, a game world can be regarded as a cradle where characters can be developed at a fast speed.

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Cheating

▶ Detecting and Preventing Online Game Bots in MMORPGs

Cheat-Resistant Gaming

▶ Secure Gaming: Cheat-Resistant Protocols and Game History Validation

Chess Variant

▶ Contemporary Computer Shogi

Children Privacy Protection

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Synonyms

Children Protection Engine; Toy Privacy

Definition

The children privacy protection aims to enable parents or guardians to be in control of their children's privacy by specifying their privacy

preferences for a toy, under the assumption that the toy has published an accurate privacy policy and complies with it in a privacy protection engine attached to the toy.

Privacy Protection Laws

Referring to the direction of the United States Federal Trade Commission (FTC), Children's Online Privacy Protection Act (COPPA 1998), and the European Union Data Protection Directive (EUDPD), a child is an individual under the age of 13 years old (Hung 2015). Children privacy protection aims to protect children's personal information, which is particularly sensitive, especially when associated with their real identity. Children provide a unique user base which requires special attention in several key areas related to their privacy (Hung et al. 2016). In general, children do not understand the concept of privacy, and hence, they tend to disclose as much information to people they can trust (Rafferty et al. 2017). In this context, the COPPA indicates that to protect children privacy, a child's personal information cannot be collected without parental consent.

Smart Toys Privacy

Nowadays, many toys on the market are becoming integrated with the sensory and networking capabilities of mobile technology, introducing new threats to privacy for children who are the primary users of these devices. Online privacy for children has been a great concern in this environment, particularly when the child's private information is involved and can be potentially shared with other parties. For example, an invention called "Google Toy" has caused many criticisms from the media as people express concern about possible privacy breaching by Google, especially with their children at home. Mattel's "Hello Barbie" has been criticized for the negative effects on children along with privacy concerns since its introduction in February 2015. In December 2015, Mattel was sued in California by two mothers to allege that Hello Barbie records their daughter's conversations without parental consent, in violation of the COPPA in the United States. Serious concerns about privacy and data security are raised by the personally identifiable information (PII) that is collected by these smart toys. These concerns are crucial since collected data involves sensitive children's information (Tang and Hung 2017).

Privacy Consequences and Precautions

While smart toys provide new educational and entertaining values, experts have warned consumers of the data security and privacy issues of these toys. A recent United States Senate report (Nelson 2016) states that these toys may gather a child's personal information, which may potentially cause serious consequences such as identity theft. Parents should be aware of the information a toy is collecting about them and their child. For most parents, it is difficult to evaluate policies regarding data collection and use since they are not usually experts with respect to data privacy and security. However, parents must find a way to reject smart toys that do not provide information about how a toymaker collects, uses, and secures their children data.

Toy Industry and Privacy

The usage behavior of children indicates that they are more open to giving out personal information, which makes issues of sensitive data sharing of great concern. The North American Toy Industry Association (TIA) released a white paper regarding the changing privacy and data security landscape the toy industry is facing with the emerging popularity of child-directed mobile apps. The TIA iterates the issues of children's marketing and privacy in this context, indicating that privacy and data security issues affect day-to-day operations of toy companies. The toy industry has also issued regulations for toy safety; however, these regulations have no mention of privacy (Hung 2015). A report from Pew Research Center and Berkman Center for Internet & Society at Harvard University indicates that most parents in the

United States are concerned about their children's online privacy, some of the main concerns being related to strangers online, and the data advertisers are collecting about their children's online behavior.

Children Protection Engine

Privacy can result in physical safety of child user, e.g., child predators. While parents strive to ensure their child's physical and online safety and privacy, they may wish to be in control of how their personal data is shared through the devices they are using. However, there is no standardized child protection model for parental control in this paradigm (Fantinato et al. 2018). Parental control is a feature in a smart toy for the parents to restrict the content the children can provide to the toy. The children privacy protection aims to enable the parents or guardians to be in control of their child's privacy by specifying their privacy preferences, under the assumption that the toy has published an accurate privacy policy and complies with it in a privacy protection engine attached with the toy (Salgado et al. 2017).

Cross-References

- ▶ Children Privacy Protection
- ▶ Smart Toys
- ▶ Toy Computing

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Children Protection Engine

▶ Children Privacy Protection

Children's Games, from Turtle to Squirtle

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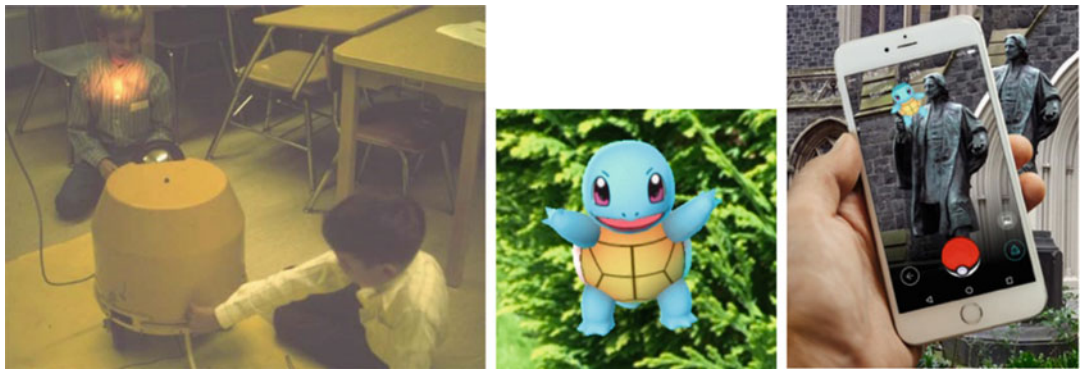
MIT 1967, *Pokémon GO* 2016

We are acutely aware that children use media all day, every day and that a part of that use is playing video games. Today four out of five US households own game consoles (Lofgren 2016) and in 2017 sales of children's mobile games alone are expected to reach $2.2 billion (Children's Mobile Game n.d.). In 2013, 38% of children who were 2 years old used mobile devices; in the two previous years, the rate of use for two to four-year-olds climbed from 39% to 80% (Rideout 2013). Now a 91 billion dollar business worldwide

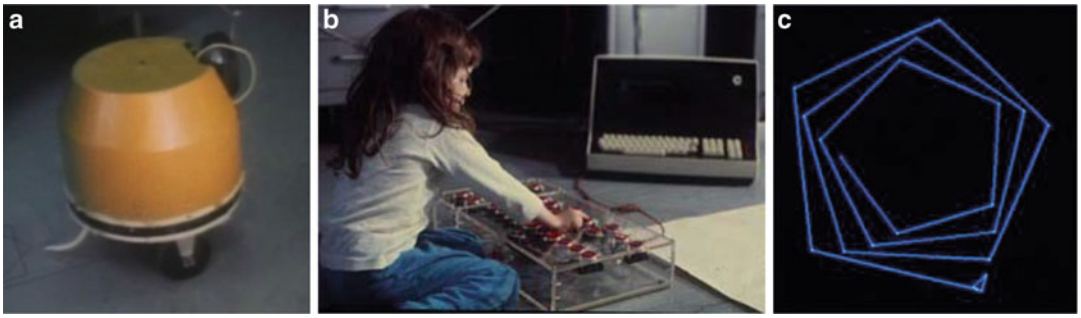


(2016) (Fuscaldo 2016), video games were first developed barely 60 years ago. Adults have long used children's games to entertain as well as educate. Plato's comments in *The Republic* (380 bce) on the value of structured play for developing young children into socially responsible and well-adjusted adults, John Locke's entreaty in *Some Thoughts Concerning Education* (1693) to make education entertaining because children "love to be busy, change and variety are what they delight in; curiosity is but an appetite for knowledge," and John Dewey's proponing in *Democracy and Education* (1922) that children learn best through experience, demonstrate to us society's ongoing desire to take advantage of children's proclivity to learn as they play (Madej 2016). It's not surprising then that children's video games had their start with a desire to use technology to benefit learning. It is also not surprising that, on their own, children prefer to accentuate entertainment over education.

Since the late 1960s, when the first programming language for children was developed at MIT, until today's mixed reality applications, games for children have travelled a continuum committed to both learning and entertainment objectives. The brief history that follows shows children's games as evolving from two different beginnings: computer applications with educational objectives for specific age groups and computer and console games designed to entertain a wide audience. The differentiation between children's and adult's games is difficult to establish because of children's facility with technology, the social nature of playing games, whether with older siblings, parents, or other children, and the nature of some games that can be played across age groups. Too, children are precocious – their nature is to challenge themselves with new things; they seldom stay within their age category for long for any activity. As an important market, children have been a motivating force in the evolution of game genres. While not all genres are covered in the following history, those discussed are representative of innovations in technology and shifts in interest that have encouraged change. These include early educational and arcade style games, handheld games, massive multiplayer online games, active games, augmented, virtual, and mixed reality games. Our trajectory takes us from the first LOGO Turtle to today's augmented reality *Pokémon Go* Squirtle.

1960s: The Very Beginnings – *LOGO* and Education Through Constructive Play

Computer play environments developed specifically for children date back to Seymour Papert and *LOGO*, the programming language released in 1967 that he and colleagues developed at MIT. Papert had studied with the child psychologist Jean Piaget in Switzerland and considered the computer an ideal tool for *learning by doing*. Using *LOGO,* children as young as three controlled a "Turtle" to create graphics (Fig. 1) (Blikstein n.d.). The program proved to help



Children's Games, from Turtle to Squirtle, Fig. 1 (**a**) First Turtle. (**b**) Buttonbox for preschoolers. (**c**) LOGO graphic

children learn complex notions qualitatively, more deeply, and with less effort (Papert et al. 1979). Papert's work was highly influential and encouraged the use of computers and software programs as a supplement to work in schools. *LOGO* spawned a number of research innovations that moved out of education and into entertainment including *LEGO Mindstorms,* a robotic system of LEGO bricks that had children building robots with motors, lights, and sensors.

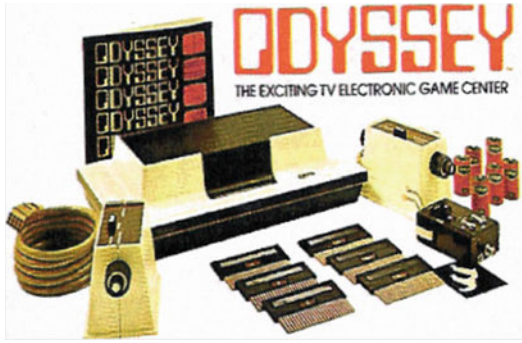
Early Interest in Education and Entertainment

Educators found that children were drawn to the active engagement computers offered and became interested in providing their students with subject-based programs to take advantage of this increased eagerness to learn. They were supported by educational organizations such as the *Minnesota Educational Computing Consortium* (*MECC*), which developed statewide systems for learning about how to use new technologies and software applications for different age groups, grade levels, and subject categories (For more information on MECC see Jancer (2016). For a list of programs available through MECC in 1983 see Atari Program Exchange Catalog (1983)). To reinforce learning at home, *MECC* sold its school software to parents and by 1983 offered more than 150 subject-related applications for children age three-and-up in its annual catalog. One of its popular school offerings, *Oregon Trail* (1978), a game about settlers who made the difficult pioneer journey from Independence, Kansas to the Willamette Valley in Oregon, became a notable success when it was released to the general public as a game title in 1985 (Wong 2017). Other programs that became popular included *DinoPark Tycoon* (1993) and *StoryWeaver* (1994).

In 1972, the first home console system, *Odyssey Home Entertainment System*, offered entertainment games based on the simple mechanics of moving light blips across the screen with a controller. Plug-in programs changed how these blips reacted to the control units and created different games. Players attached gameboard overlays to the television screen and could play, among other games, *Tennis, Hockey, Football, Cat and Mouse*, and *Haunted House* (Fig. 2). Educational topics were also included: players could, for instance, learn the names of the US states. *Odyssey* games included poker chips, play money, and score cards that completed the game play experience. The system inspired *Atari's* Nolan Bushnell to create *Pong*, the popular game in which players use paddles to hit a ball back and forth (Winter 2013).

Edutainment

By the early 1980s, PCs began selling in the millions and were being advertised as *family*

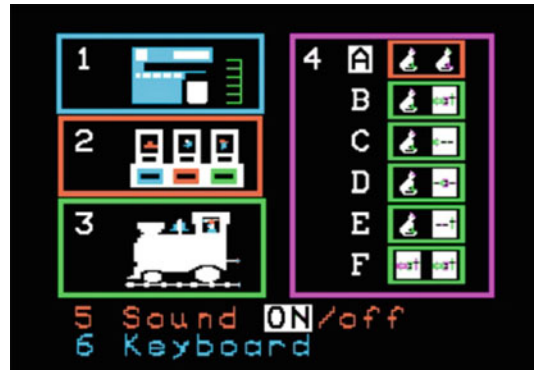


Children's Games, from Turtle to Squirtle, Fig. 2 The *Odyssey Home Entertainment System* (1972)

Children's Games, from Turtle to Squirtle, Fig. 3 Family computer systems were advertised for both education and entertainment

computer systems that could be used both for education and for entertainment. Ads often showed parents playing together with their children as a family. Video games were on their way to becoming a fixture in children's daily lives (Fig. 3).

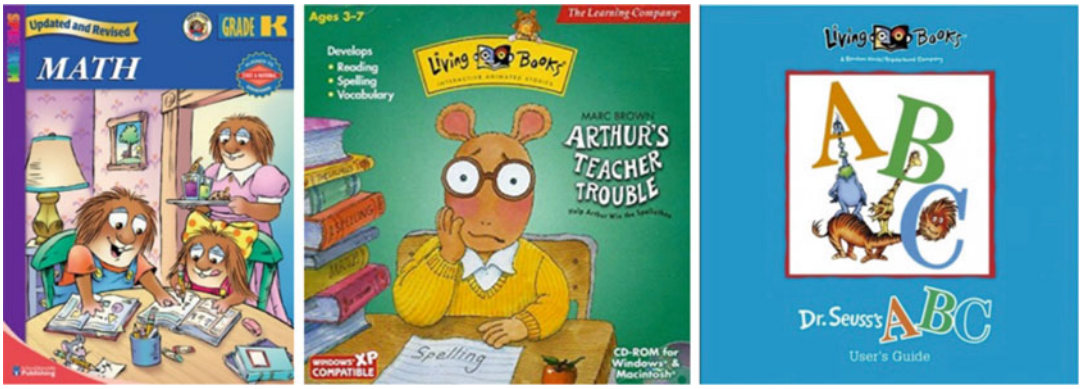
Publishers and game developers noted the success of education-related titles and began to intentionally combine entertainment games and education software to create *edutainment*, software that could be marketed as both entertainment and education. *The Learning Company* and *Broderbund* were two companies that began to create and promote entertainment-based educational games from different perspectives that still prevail. The Learning Company was started as an educational software developer. Its first commercially developed edutainment title, *Reader Rabbit* (1983), designed for elementary school children



Children's Games, from Turtle to Squirtle, Fig. 4 *Reader Rabbit*: Menu Screen (1984)

by cofounder Dr. Leslie Grimm, set the pattern for educational series. Using stills, simple animation, and music, the click and point games engaged children in learning about language. Children picked individual letters, or combinations or sequences of letters, to complete activities and were rewarded with a jumping/tumbling bunny and congratulatory sounds (Fig. 4) (Reader Rabbit and the Fabulous Word Factory n.d.). Successful Learning Company titles included *Clue-Finders, Mind Power, Zoombini's*, and *Super Solvers*. Each targeted a specific age-group and a subject area (The Learning Company n.d.). The company aimed to interest parents in improving their children's skills and knowledge.

Broderbund (1980), on the other hand, started as a commercial game developer (*Prince of Persia, Myst).* It moved into edutainment titles in 1985 with the detective game *Where in the World is Carmen Sandiego*. The company's approach to edutainment was story rather than arcade-skill based: in Carmen Sandiego children were set the task of finding Carmen and travelled around the world asking questions that would lead them to the thief. This narrative approach had more in common with text adventures than with arcade action. After the initial success with *Carmen*, Broderbund founded *Living Book*s, a series of interactive CD-ROM storybooks that engaged children through click and point animations. It brought well-loved print stories – Mercer Mayer's *Just Grandma and Me* (1992), Marc Brown's *Arthur's Teacher Trouble* (1992), Stan



Children's Games, from Turtle to Squirtle, Fig. 5 Lil Critter helps his sister with her math, Arthur worries about his spelling, Dr. Seuss's ABC's

and Jan Berenstain's *The Berenstain Bears Get in a Fight* (1995), *Dr. Seuss's ABC* (1995) – to an audience who enthused about the new game-like interactivity in these stories. Game publishers soon adopted popular story characters to bring their appeal to education-related topics such as reading, writing, math, art, puzzles, and thinking (Fig. 5).

Evolving Entertainment and Edutainment for Computers and Consoles in the 1980s

Entertainment games evolved along two main paths in the late 1970s – as arcade-action games and as text adventure games. In an arcade-action game, although the game might consist of cause and effect events, it did not require a story to be successful. By the early 1980s, original *Pong* action had evolved and included: maze games – *Pac-Man* (1980), players needed to avoid four ghosts while eating up all the dots; platform games, called climbing games at the time – *Donkey Kong* (1981), players jumped obstacles and enemies through four different levels; and simulation games – *Star Trek: Strategic Operations Simulator* (1982), players had to defend the Starship Enterprise from Klingon invaders.

Text-adventure games, on the other hand, were based in story. Players achieved their goals not by repeating arcade-type actions but by asking questions of game characters, unlocking secrets, and overcoming obstacles to reach a goal. As *Spacewar!* (1962) gave rise to all later action games beginning with *Pong*, *Adventure* (1975) became the first text adventure game that spawned all other text adventures. Popular in university and corporate intranets, *Adventure* was initially created to be shared with children. Will Crowther, the designer, writes "I decided I would fool around and write a program that was a re-creation in fantasy of my caving, and also would be a game for the kids [his two daughters], and perhaps some aspects of the Dungeons and Dragons that I had been playing…. The kids thought it was fun" (The origins of "Adventure," Crowther n.d.).

As the game market grew and as technology evolved, exploration in different game-like experiences for children increased. When *HyperCard*, an easy to use software programming tool was introduced by Apple in 1987, Amanda Goodenough used it to create *Inigo Gets Out* for younger children. This first graphical hypertext lets children explore a space the cat *Inigo* inhabits and move the story forward by clicking not on the object of action (i.e., the cat), but on where the object needs to move. For instance, clicking at two birds will make *Inigo* jump at them. Published by *Voyager,* the simple narrative opened the eyes of artists and designers, as well as writers, to the possibilities of making their children's stories interactive (Fig. 6) (Madej 2007).

While Goodenough, a writer, was creating with hypertext for young children, Roberta Williams, a game designer, was developing the first edutainment graphical adventure game, *Mixed-up Mother Goose* (1987), to entertain and educate her two preschoolers. Williams had set up *Sierra Online* with her husband Ken and they had created the 10+ adventure series *King's Quest* (1984). Based in stories, many adapted from traditional fairy tales or adventure tales, *King's Quest* was the first game to introduce third-person play; until that time players played in the first person. The third-person position allowed the player an important choice – to think about the character either as her/himself, or as a separate character altogether (DeMaria and Wilson 2002). In *Mixed-up Mother Goose* young children play as one of eight characters that searches for lost items throughout the land and returns them to help story characters out of their predicament, i.e., they could help Mary by bringing back her lost lamb (Fig. 7). When completed successfully, the task was rewarded by a congratulatory animation/sound. In contrast to *Reader Rabbit* published four years earlier, children could visualize themselves in the story through the avatar, could explore the space, and could interact with story characters. Other mechanics such as picking up the clue, dropping it off, and being rewarded by an animation were based on existing types of actions. Together these sets of click and point actions became characteristic of children's games, and indeed of many adult games.

Children's Games, from Turtle to Squirtle, Fig. 6 *Inigo Gets Out* title screen

In 1986, *Walt Disney* released *The Black Cauldron* based on its animated film of the same name. The company made the game to be more child-friendly than other games of the time; designer Al Lowe simplified the game commands by replacing the text parser with function keys to make it easier for children to play the game, an innovation not used again for a number of years. Lowe followed the original story and provided more decision-making choices by adding new plot branches and six endings. Sierra's expertise in graphics made the game visuals more realistic and appealing than the linear and stark graphics of other games (Fig. 8) (Lee and Madej 2012).

Animated movies were a natural source for children's action-based games as their storylines already consisted of action that designers

Children's Games, from Turtle to Squirtle, Fig. 7 *Mixed-Up Mother Goose* of the rhyme, *Mary Had a Little Lamb*

Children's Games, from Turtle to Squirtle, Fig. 8 *Black Cauldron* graphics (*left*) versus *Dark Crystal* graphics (*right*)

could mine. The puzzle game *All Dogs Go to Heaven* (1989), the side-scrolling platform game *Aladdin* (1993), and the action-adventure *Casper* (1996) featured only action sequences rather than the entire story. Live films were also used to inspire action adventure games suitable for children. As is the case with animated films, most games use the story plot only loosely to take players through action sequences. In *The Karate Kid* (1987), for instance, the player uses karate moves on four levels and ends with Master Miyagi congratulating him/her on learning the moves needed to help Daniel successfully meet all the challenges (See a partial list of movies made into video games at https://en.wikipedia.org/wiki/Category:Video_games_based_on_films, Great video games based on movies n.d.).

The first video game that featured animation as polished as in animated movies was *Disney Interactive*'s *The Lion King Animated Story Book* (1995). Media Station, the developer, used breakthrough technology and skillful editing to ensure the original quality and continuity while affording interaction. Designed for children 3–8, the game became popular with children as well as adults who had enjoyed the movie. Other *Interactive Storybooks* based on Disney animated films followed: *Winnie the Pooh and the Honey Tree*, *Pocahontas*, *The Hunchback of Notre Dame*, and *Mulan*, among others.

A game phenomenon that began in the 1980s and grew to great popularity in the 1990s was the simulation game. Simulation games had grown out of educational games such as *Oregon Trail* (1978) that had been designed to simulate real world activities and provide players with a greater appreciation of the real life events. The success of *The Sims* in 1990 and of *Railroad Tycoon* in 1993 encouraged the development of simulation games for children such as *Harvest Moon* (1997). In this game, children were responsible for allocating their time to best maintain a farm that had fallen in disrepair. They were provided daily tasks to complete, different environments to explore, and, among other things, weather to contend with. Simulation games such as this one were "learning in context," and fit the genre, although were not always labeled, edutainment.

Such a learning simulation game that leads us into the next topic, handhelds, is *Nintendogs* (2005). Handhelds are particularly suited to providing children a means to carry out set tasks in real time. In *Nintendogs*, children take care of their pet dog on the Nintendo DS. Using the touchscreen, they can train their dog, take it to the park, and wash and brush it. They can also record commands that the puppy should obey if it has been trained correctly. A real-time simulation, the action is based in the DS's calendar and clock so, for instance, a puppy would grow hungry if not fed on time; the game provides feedback for acting responsibly toward a pet.

Handhelds Prepare the Way

During the 1980s, handheld games gained tremendous popularity. Small and easily

transportable, they could be used anywhere from the sofa to the car seat; playing video games no longer kept children tied to computers at a desk or console – a large part of handhelds' charm for both children and parents. Introduced at the beginning of a new era, when parents trekked their kids from activity to activity in that other phenomenon of the time, the mini-van, handhelds became a part of children's everyday life and probably more than any other game technology were the determinant of today's generation of digital natives.

Handhelds had their origin in the single game electronic devices of the 1970s, such as *Auto Race* (1976) and *Football* (1977) made by the toy manufacturer Mattel. When Nintendo introduced *Game and Watch* in 1988, a single game format with one small screen and two or four buttons, it had similar simple game action that also challenged skills. The games were both educational and entertaining: *Flagman* (1980) was a memory game in which the character on screen showed a random number the player had to memorize and input into a series of squares. The format's popularity was increased through games that featured well-known cartoon and video game characters such as *Mickey Mouse* (1981), shown in Fig. 9, *Popeye* (1981), *Snoopy* (1982), *Donkey Kong* (1982), and *Mario Bros* (1982), who brought their own background stories as context and backdrop for the games (RolyRetro 2016).

The success of Nintendo's next handheld system, *Game Boy*, introduced in 1989, is based on the popularity of its games rather than in any sophisticated technology. In comparison to its competitors, its green screen was blurry and graphics were unimpressive, yet it became the most successful video game system ever – handheld or otherwise – because of its strong stable of notable games. It was released with what became the most popular game of all time, *Tetris* (Melanson 2006), and then featured a wide spectrum of game genres: puzzle games – *Boxxle (1990),* adventure games – *Who Framed Roger Rabbit* (1991), historic action adventure games – *Prince of Thieves* (1991), sports games – *Ultra Golf* (1992), fighting games –*Street Fighter II* (1995), pinball games – *The Getaway: High Speed II* (1995), racing games – *Street Racer* (1996), and side-scrolling platform games – *Toy Story* (1996).

Children enjoyed playing these games – parents saw their children were not only occupied but were also learning new skills: a win-win situation that helped establish playing handheld games as a go-to activity, one that translated readily to playing games on mobile phones, when that technology became available.

The most recent iteration of mobile gaming that continues children's (and adults') enthrallment with this genre of game play is the Nintendo *Switch* (2017), a hybrid console that can be played on-the-go as a handheld or on a TV at home. It consists of a main unit with Joy-Con controllers attached to each side that can be slid off so the

Children's Games, from Turtle to Squirtle, Fig. 9 In *Game and Watch*, Mickey runs to catch eggs falling from one of four chutes

screen can be propped up on a table for one- or two-player games. The Switch system also includes a charging cradle so games can be played on a big-screen TV. The design allows for players to get the same basic experience regardless of how they play (Thang 2018).

The Internet Introduces Community to Children's Games

At the same time as handhelds were keeping children enthralled in the world of desktop computers, the internet was changing into a user-friendly place that was opening up doors for gaming of a different nature. In 1994, Netscape Navigator brought the graphical user interface to the general public and changed the face of the World Wide Web both for adults and children. At the time, edutainment CD-ROMs were at their height. As children's authors took advantage of the new technology to create edutainment websites such as *Banph, Chateau Meddybemps, Fablevision*, and *Little Critter World-Wide Network* (Fig. 10), based in their own work, the industry faltered and would never again be so financially successful. All of the activities CD-ROMS provided were now available online, if perhaps not quite the same quality, for the cost of a service provider (Madej 2007).

Online access also popularized Massive Multiplayer Online Role-Playing Games (MMORPGs), which, at the time, were considered an adult genre. In 1996, *Starwave Corporation* brought the genre to children 8+ with the game *Castle Infinity*. Entertainment video games had over the years stirred up considerable controversy with addictive and violent game play dominating the discussion; diverse opinions were held about the value of games for children. Multiplayer online games were equally suspect. *Castle Infinity* promoted the use of nonviolent ways of problem solving: how to get rid of monsters who were threatening the last of the dinosaurs in their home, the Castle. Children used a password and a unique name to join players around the world in cooperatively saving the dinosaurs.

Into the fray of concern about online entertainment *The Disney Company* launched an ambitious site for children, *Disney's Daily Blast* (1997). The site offered parents a gated environment in which their children could connect with each other safely. Attractively designed to be child-friendly, the site offered a changing range of stories, comics, arcade games, and educational games for online play, either alone or with chosen friends (Fig. 11). Multiplayer games included the musical activity *Music Room Composer,* in which children could compose and record music, share music with friends who could comment on the composition, and play in jam sessions (Lee and Madej 2012).

Children's Games, from Turtle to Squirtle, Fig. 10 *Chateau Meddybemps* and *Little Critter World-Wide Network* with games, puzzles, and stories

GAMES STORIES ACTIVITIES CHARACTERS MAIN EVENTS PARENTS EXIT
SKIP INTRO
BLAST DOME
BLAST JR
Newton
Change User
Contact Us | Privacy Policy | Internet Safety
Use of this site signifies your agreement to the terms of use. © Disney. All rights reserved.

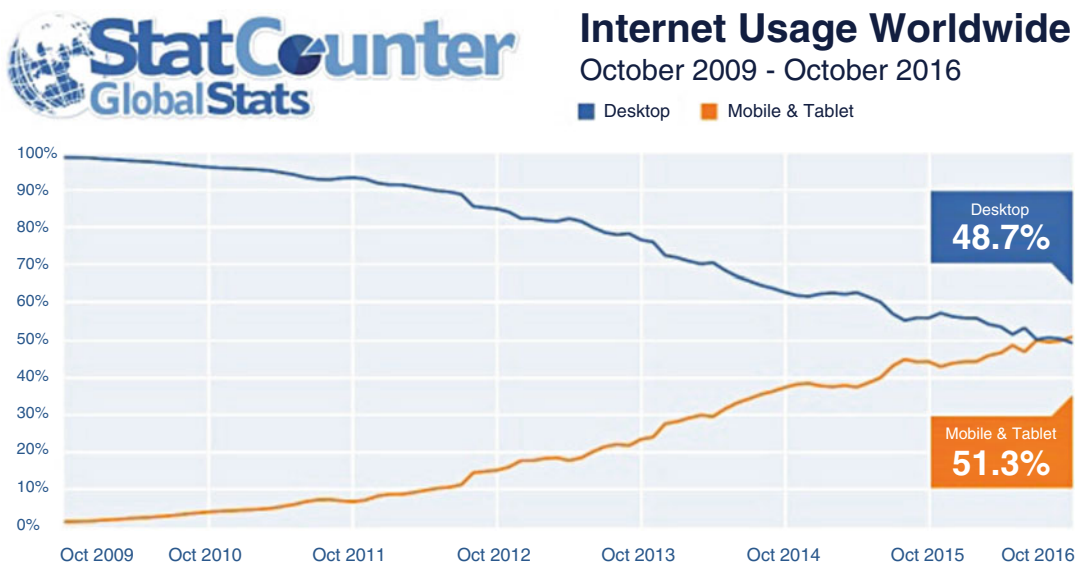
Children's Games, from Turtle to Squirtle, Fig. 11 *Disney's Daily Blast* presented a child-friendly portal page to a gated environment

By the 2000s, the major children's publishers and media companies, from *PBS Kids* to *National Geographic Kids,* realized the promotional opportunities of engaging children online, and created sites that were based in children's favorite characters and stories such as *Arthur, Caillou, Clifford, Dragontales,* and *Sesame Street.* These sites offered learning opportunities through entertainment, although initially they did not offer a multiplayer environment.

Today, many games are available in versions that can be downloaded from the Internet. The sandbox game *Minecraft* (2010), for instance, which is now the second most popular game after *Tetris,* can be purchased for single play or can be played online with friends. A sandbox game is an open-world game akin to playing with *LEGO* blocks and building objects or scenes, only the number of blocks is limitless. In *Minecraft*, children 6+ decide for themselves what to do and how to do it. They collect materials available in the space and build whatever their mind can imagine. As online friends they can cooperate to build worlds together.

Changing Handheld/Mobile Landscapes

Mobile technologies brought the connectivity of the internet to the portable handheld. Tablets replaced desktops and laptop computers for children in many homes. Their small size, portability, relatively low cost, and Wi-Fi connectability made them a practical device for playing favorite games, including online games, anywhere in the home, or indeed, even away from home. The smartphone has quickly replaced even the convenience of the tablet for Wi-Fi access (Fig. 12)



Children's Games, from Turtle to Squirtle, Fig. 12 Up from 2016, shown above, 2017 stats indicate mobile use continues to increase. Mobile – 52.29%, Desktop – 43.29%, Tablet – 4.42%

(Mobile and Tablet Internet Usage 2016). It is useful to parents, engaging for their children, and is ever present. Easy availability and mobility, together with the fact that, like a handheld, a smartphone fits a child's hands well and has a responsive touch screen (tablets have this as well), makes it a most advantageous digital entertainment device for on-the-go parents who want to occupy their children. In addition, game developers have been assiduous in fulfilling parent's requirements for educational games and children's need for entertainment games both for IOS and android tablets.

Mobile games for children, while limited by the speed of the technology and the size of a device's memory, were initially not much different from what children had available to them on a desktop or laptop computer. A traditional edutainment game for mobile devices, *Brain PoP: Today's Featured Movies,* for instance, uses internet connectivity to present a new set of movies each week about topics from math to social science. Children choose their topic and accompanying movie, watch, and then answer a pop quiz. Whether either at the behest of their parents or on their own, children are learning the alphabet, learning coding through puzzles and games, or learning to speak Spanish by saving trapped toys, they have access to hundreds of applications through dozens of websites specifically for learning or identified as just-for-fun (during which learning does go on). An example of a popular (most downloaded game of all times) game is *Angry Birds* (2009). A puzzle, turn-based game for ages 8+ in which cute birds aim to retrieve their eggs from some greedy pigs, it has no new types of interactivity, but does have engaging characters in fun and wacky side-scrolling gameplay (Cheshire 2011). *Angry Birds* has translated well into cross-media activities such as children's library programs and use in early learning environments such as preschools. *Cut the Rope* (2010), in which players must feed a little green creature, Om Nom, with candy they retrieve from hanging ropes, requires more challenging planning and dexterity in use of the touch screen to cut the rope. It is also popular across media so that children have opportunities to transfer their mobile knowledge to physical play (Fig. 13).

Mobile devices have become very popular with parents for very young children as well. Designers have put such technology as the touch screen to great advantage in games for them. In

Children's Games, from Turtle to Squirtle, Fig. 13 Playing *Cut the Rope* on a smartphone requires planning ahead and dexterity. Cross media marketing, for this as for many other games, has provided players with real world artifacts for interacting with Om Nom

Old Macdonald (2009), for instance, young children can use their fingers to push a tractor, open barn doors, jump with frogs, pop balloons, and swish their way through the rhyme as the tune plays to the animations. Together with parents or alone, children can also read, listen, and record themselves singing. This engages them not only cognitively but also physically in their play activity, creating stronger connections in their learning (Madej 2016).

Tangible Games

The most recent developments in tablet and smartphone games, virtual reality (VR), augmented reality (AR), and mixed reality (MR), are at the end of a trajectory of evolution in action video games that, during the mid-1970s, took the form of accessories such as racing wheels, and today, has players moving about the neighborhood, the city, or even the world, searching and catching virtual Pokémon. While manifested in different ways, the main purpose of action games is to provide tangible or embodied interaction that engages the player physically and simulates real world activity. This could be by providing haptic feedback, physically engaging interaction, an immersive environment, or by augmenting an existing environment.

Among the first live-action games were racing games and marksman games. Although entertainment oriented, many of these games required children to improve skills to acquire higher scores or

Children's Games, from Turtle to Squirtle, Fig. 14 The Coleco *Telstar Arcade* (1976) with its racing wheel and pistol

reach new levels of ability. Coleco's *Telstar Arcade* (1976) (Fig. 14) exemplifies early interest in creating a simulated experience for home video games. The three-sided *Telstar* featured two sides that provided for a "real experience." Players controlled a racing wheel while playing racing car games on one side, or drew and fired a pistol for target shooting on another side. On the third side, players used typical game buttons to control pong games such as tennis (Madej 2007). Racing wheels continue to be used and are still bundled with racing games for systems such as *Mario Kart Wii* (2008).

New types of interactive artifacts that engaged children physically were introduced in the late 1990s and early 2000s. These included play

mats on which children could enjoy dancing to the music video game *Dance Dance Revolution* (1998), konga drums they could beat in *Donkey Konga* (2003), and guitar controllers they could strum in *Guitar Hero* (2005). Each of these interfaces required improving skills to reach the next level of proficiency and provided for learning while playing.

While mixed reality appears to be a very recent phenomenon in children's video games, it was first seen in Sony's *EyeToy:Play* in 2003. Sony used an inexpensive webcam to literally put the player into the game through motion capture video. Players could dance, Kung Fu, wash windows, play soccer, or box against themselves. While *EyeToy* caught the imagination, it was difficult to get the actions right to appear on the screen. This difficulty caused frustration. It wasn't until the *Wii* console system, which detected the player's movement in three dimensions, was introduced by Nintendo in 2006 that motion capture gameplay became seamless and enjoyable rather than frustrating. Both Wii arcade games and its narrative games used the technology to advantage. In the medical drama, *Trauma Center: Second Opinion*, the player, as Dr. Derek Stiles, sets broken bones, cleans and stiches wounds, and simulates the use of a defibrillator during an emergency situation: he has to "shove the two controllers forward to shock [the] patient[s]" (Fig. 15) (Trauma Center 2006).

Wii games were promoted for children as young as toddlers and games like *Kirby's Return to Dreamland* were positively viewed as family friendly because of their multiage, cooperative play. But toddlers and preschoolers found the controls difficult, both in this and other games such as *Reader Rabbit Kindergarten* in which any precision was required (Healy 2011). Issues also arose when Microsoft introduced the next motion capture device to come on the market, the *Kinect* (2010). Older children could engage in simulated action in games but problems existed with recognition of younger children because of their height, as well as with light levels, the amount of space required to play, and recognition of movements (Kinect Sucks for Little Kids 2012).

Mixed reality games entered a new era when they began to include either or both VR and AR in their mix. Virtual glasses such as Google Cardboard, a simple, inexpensive version of a VR headset, became an asset in the development of immersive adventures for children. Edutainment benefitted in particular in games such as *Jurassic Virtual Reality* (2014), in which children go back to the time of the dinosaurs and can observe the creatures in their natural habitat from any angle. The ability to engage in a very personal way within an environment makes learning immediate and takes edutainment to a new height.

Children's Games, from Turtle to Squirtle, Fig. 15 Wii *Trauma Center* requires players to simulate real-world action

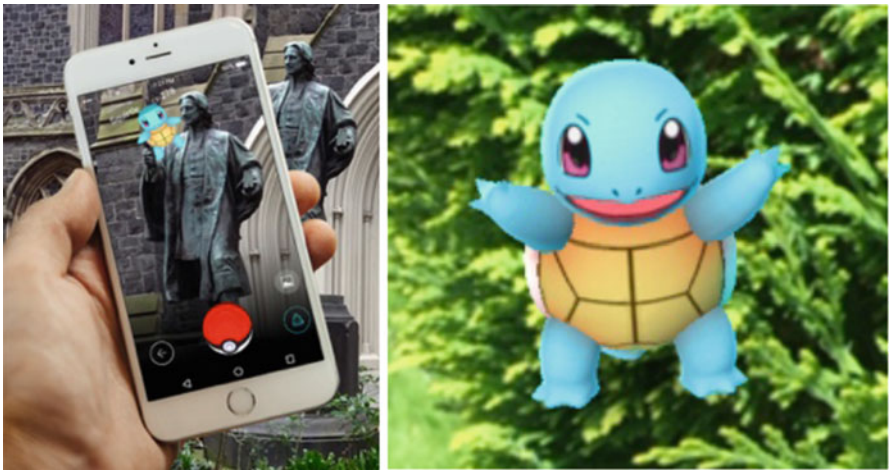
Children's Games, from Turtle to Squirtle, Fig. 16 (**a**) *colAR/Quiver* character, (**b** & **c**) *Toy Car RC*'s Western World brought to life through AR

In September 2013, *colAR Mix*, now called *Quiver*, was announced as an AR coloring experience for children. This application let children bring characters they colored on pages printed from the app to life in 3d when they are viewed through a tablet or mobile phone and added an engaging new experience to traditional coloring (Fig. 16a). Each new MR application seems to raise the bar for engagement: *Toy Car RC* (2014) for children 6–8, follows the adventures of a small car named Wheely that is always searching for an adventure. Once children print out and position target pages in a space, they set Wheely on his journey and connect the real world with a virtual world, either Candy Land or Western World (Fig. 16b, c).

The AR game *Pokémon GO* (July 2016) brings us to the end of the trajectory of action games, at least for our present time frame. It is also where, for the moment, this brief history of games ends. *Pokémon GO* has taken what is the most used platform for games, the smartphone (which we carry with us everywhere), paired it with well-loved and storied characters (which few, if any, of us have not heard of), and simply asks of players that they look around their natural environment to find and collect Pokémon and then share these collections with others. *Pokémon GO* is currently being used for classroom assignments: children "Keep a log of where they go, what they see, and what they are learning as they play, including historic places and points of interest" (Gracey 2017). But a classroom situation isn't needed to spark interest in learning for children who search for Charmander, Bulbasaur, or Squirtle (Fig. 17). While Rolling Stone says *Pokémon GO* is "a free-to-play, location-based, augmented reality, multiplayer online mobile game that also supports its own custom wearable tech" (Davison 2016), more humanistically speaking, and more to the point, through its enthusiastic embrace of engagement with the real world *Pokémon GO* shows how technology, story, and environment can be joined effortlessly to engage us communally in an entertaining game that engages children in learning.

Finally

In 2017, 60 years passed since the *LOGO Turtle* was first introduced to the world. Seymour Papert's interest during the 1960s in creating a playful environment with computer technology to benefit children's learning continues to be pursued with vigor by the games industry today. Through an unflagging continuance of effort, and whether developing games solely either for learning or play, or developing games intended to do both, the different streams that have evolved are exploring technologies as quickly as they are emerging and taking advantage of new types of engagement to offer a mix of learning experiences. While some may not see searching for *Squirtle* as beneficial to learning, others have taken the idea, and exploited its potential to engage a generation of children, many of



Children's Games, from Turtle to Squirtle, Fig. 17 *Pokémon GO*: Searching for *Squirtle*

which, have never been without a digital gadget in their hands.

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Choices in Games

▶ Domain-Specific Choices Affecting Design Effort in Gamification

Circles Space

▶ Theory of Minkowski-Lorentz Spaces

Citizen Science

▶ Games in Science

Classical Learning Method in Digital Games

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Synonyms

Genetic algorithm; Machine learning; Neural networks

Definition

Classical learning includes simple neural networks, genetic algorithms, and so on. Few game titles utilize classical learning because these must be harmonized with game design. Thus, the main problem of implementing the classical learning method in digital games is finding out how to synergize a classical learning algorithm and game design.

Introduction

Learning has not always been used in digital games; rather, it is used only in specific and limited contexts. There are two reasons for why the application of learning is limited. First, the game is usually developed on a game design, and it is adjusted to be strict good balance by a game designer's sense. Learning AI method introduces unpredictability and variations. It is considered difficult to combine learning algorithms with game design. To address this, advanced game design technologies that absorb the fluctuations of learning algorithms and engineering technology to safely control learning are both needed. Second, learning requires CPU and memory resources, which sometimes puts heavy load on graphics and other game characteristics. However, the latter is gradually being addressed by improvements

to the computing performance of the game and development machines. Accordingly, learning algorithms are being incorporated gradually into games and game design.

In the 1980s and mid-1990s, when artificial intelligence (AI) technology was used, it almost completely exhausted the memory and CPU resources available for the game. Thus, these were marketed as "AI Games." Some examples include enjoying a conversation with a virtual woman in "Emmy II" (ASCII, 1984), training a puppy in "Puppy Love" (Addison Wesley Publishing), simulating the life of a family in "Little Computer People" (Activision, 1985), and simulating the life of a girl in "Appletown Story" (Square, 1987).

Towards the latter half of the 1990s, the performance of game machines improved reasonably. Accordingly, AI algorithms such as "Genetic Algorithms (GA)," and "Neural Networks (NN)" were gradually incorporated into games. Large-scale neural networks on the order of a few thousand nodes were utilized to allow players to teach creatures "Creatures" (Millennium Interactive, 1996), where the characters in the game were taught to use objects within the game. Moreover, in the PlayStation, AI game masterpieces by Mr. Yukihito Morikawa of muumuu continued to be released (Morikawa 1999). "Ganbare Morikawakun 2gou" (English title: Pet in TV) (muumuu, 1997) was a game for imparting intelligence to "Morikawakun 2gou," where the intelligence in Morikawakun 2gou was inculcated through the learning of instructions from players utilizing a back-propagation neural network. Moreover, in "Astronōka" (muumuu, 1998), the performance of the enemy characters was designed to evolve according to the way the players play by utilizing a GA. In the 1990s, the reverberations of the second AI boom were late in infiltrating the game industry.

In the 2000s, the number of "AI games" gradually reduced with the rapid development of 3D graphics. There was a gap of several years before learning started to be incorporated into specific areas within a game. "Black & White" (Lionhead Studios), which was released in 2001, is a game in which the user leads the inhabitants and make them thrive. Simple neural networks (perceptron, three for input, one for output) are set for the creatures, which learn depending on the discipline enforced by the user (Evans 2002). In this manner, they learn what actions to take depending on the motivation. In the "Forza Motorsport" (Turn 10 Studios, 2005) series, a mechanism called Drivatar was introduced to learn the user's driving technique (Microsoft Research 2014). This was a type of "machine learning" that automatically learned deviations from an ideal racing line set for each course; the learnings were used as a parameter of "steering handling." Moreover, as an example of related research, at Microsoft Research, (2004) the AI in the fighting game "Tao Feng" (Studio Gigante, 2003) was successfully improved by using the Q-Learning method, which is a type of reinforcement learning realized through interactions with players (Herbrich et al. 2008; Graepel et al. 2004).

With respect to targeting (selecting enemies), among the AI techniques, one example of the use of neural networks in the 2010s, is "Supreme Commander 2" (Gas powered Games, 2010) (Robbins 2013). It learns which enemy to target around the character, from approximately 60 min of play by the developer, by using back-propagation. Moreover, in "Killer Instinct" (Rare Ltd., Iron Galaxy Studio, 2014), the case-based reasoning method is adopted, where AI play is set up by using play data from users (Hayles 2015). Moreover, although its development was cancelled, in "Fable Legends," Monte Carlo Tree Search (MTCS) was used to locate the positions of enemy groups (Mountain 2015) (Fig. 1).

Thus far, some examples of the application of evolutionary learning algorithms have been described; however, the reality is that, until 2018, the number of "cases of clear application to a game" was very small. Although the application to games is described in the next section,

Year	Title	Method
1996	Creatures (Mullennium Interactive)	Neural Network
1997	Ganbare Morikawakun 2Gou (muumuu)	Neural Network
1998	Astronoka (muumuu)	Genetic Algorithm
2004	Tao Feng (Studio Gigante)	Q-Learning (Reinforcement Learning)
2005	Forza Motorsports (Turn 10 Studios)	Machine Learning (Statistical Learning)
2010	Supreme Commanders 2 (Gas powered Games)	Neural Network
2014	Killer Instinct (Rare Ltd. Iron Galaxy Studi)	Case-Based Reasoning
2015	Fable Legends (Lionhead Studio)	Monte-Carlo Tree Search

Classical Learning Method in Digital Games, Fig. 1 Examples of the application of learning and evolutionary algorithms to games (main unit)

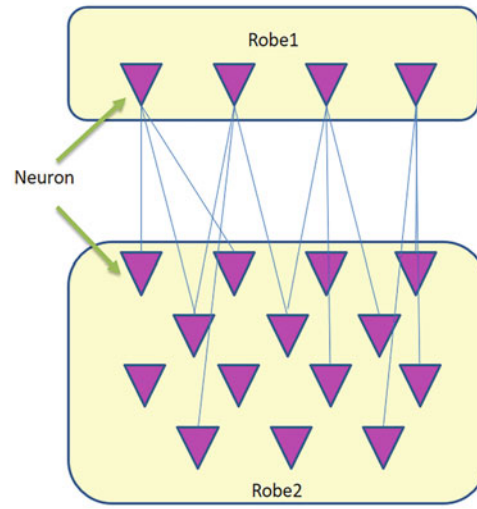
there is a rapidly increasing trend. Even though the performance of game machines continues to increase, the problem regarding where this should be incorporated in the game design still remains a formidable challenge. We discuss each of the cases.

Neural Network in "Creatures"

Because "Creatures" (Millennium Interactive Ltd, 1996) is a game for personal computers that was released in the 1990s, it is not well known in Japan; however, it is well known internationally, and has been highly evaluated, winning many awards. It is a game in which creatures called "Norn" are raised, and in particular, they can learn language as well as the names of the objects and actions inside the game. Once learning is complete, simply by providing a word, they can be made to perform the corresponding specific action.

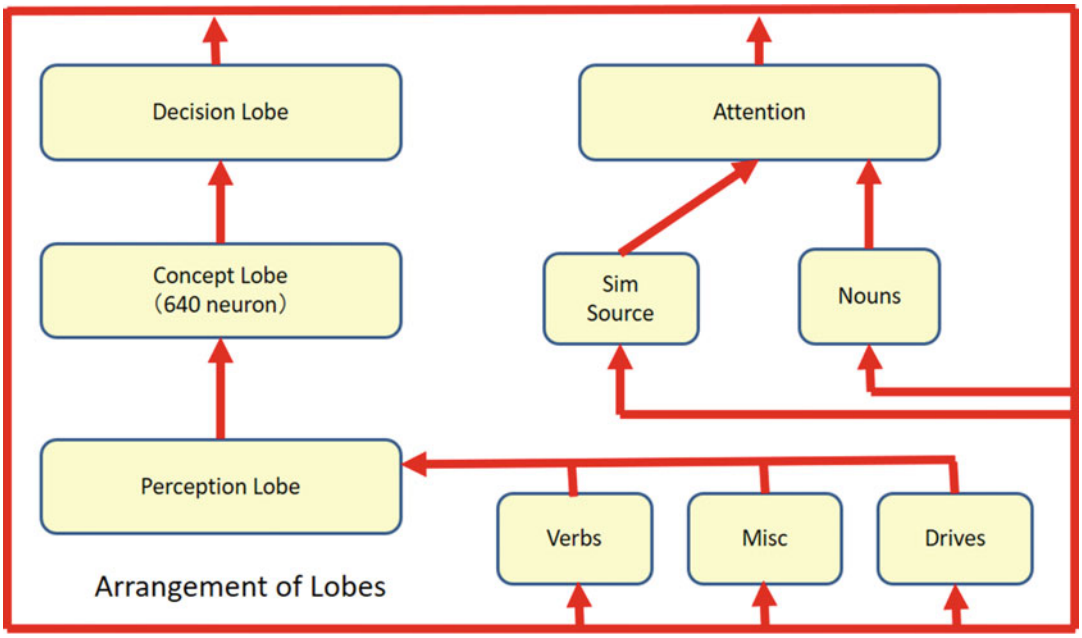
At that time, the brain of a Norn consisted of a neural network comprising a few thousand nodes. A set of neurons is called a "lobe," and neurons in each individual lobe are interconnected with neurons in other lobes (Grand and Cliff 1997) (Fig. 2).

The intelligence of Norn is based on the agent architecture. The sensory lobe senses external signals. For example, when a ball is seen, the neurons responding to the ball become active. The user shows various objects to the



Classical Learning Method in Digital Games, Fig. 2 Unit of Norn brain "Robe"

Norn, upon which the attention lobe responds. The Norn then says the name of the target object (noun) or the action (verb) corresponding to the behavior. The user by using a mouse gently caresses the Norn when a correct answer is provided or slaps it when the answer is incorrect. In this manner, the neurons in the neural network learn the nouns and verbs used in the game. The users can also enter the words. The neural network learns by matching the target with the word, or the action with the word (see Fig. 3).



Classical Learning Method in Digital Games, Fig. 3 Schematic of lobe (neural network) in "Creatures" (Grand et al. 1996)

Learning and Evolutionary Algorithms in Japanese Game Scenes in the 1990s

The second AI boom is said to have occurred during 1984–1994. Accordingly, its effect was still observed in the latter half of the 1990s. In the gaming industry, in the late 1990s, with a slight delay, various games using AI were released. "Creatures" was one such game. In the Japanese gaming industry, two games using AI were released in the late 1990s, "Astronōka" and "Seaman" (SEGA, 1999). Yukihito Morikwa developed the former, and Yutaka Saito developed the latter game. The characteristic of AI used in the games during this time was that AI attributed to a large proportion of the total content since a large portion of the resources needed to be allocated to AI. This implies that other elements such as game design and CG were closely intertwined with AI. In such games, a game creator was required to design the game consistently, from the game design to the technology adopted. Both Morikawa and Saito undertook such a design process to integrate the game design with AI.

Learning algorithms were incorporated into a series of AI games created by Morikawa:

Back-propagation neural network in "Ganbare Morikawakun 2gou" (SIE, 1997)

Genetic algorithm in "Astronōka" (SQUARE ENIX, 1998)

Back-propagation neural network in "Kokohore! Pukka" (English title: Dig a-Dig Pukka) (SIE, 2000)

Autonomous lyric generation in "Kumauta" (SIE, 2003)

In "Ganbare Morikawakun 2gou," specifying a behavior (action) corresponding to an object discovered by a character, enables it to undertake appropriate behavior corresponding to the sense of perception of the character about the target object. In "Kokohore! Bukka," the player teaches the agent the type of stones to be dug out through a reward system, the agent gradually starts judging the stones by itself. In "Kumauta," the agent autonomously creates lyrics corresponding to the lyrics selected by the user, which the white bear then sings in the enka style.

A short introduction to "Astronōka," where a genetic algorithm is used, is given below.

Genetic Algorithm in "Astronōka"

"Astronōka" uses a genetic algorithm to help the enemy characters evolve. The players cultivate vegetables and set "traps" in the field to exterminate pest characters called "baboo" that harm the vegetables. The "traps" are regions divided into a grid-like mesh, where players can place fans, scarecrows, or pitfalls to trap the pests.

In the latter half of the 1990s, the media reported on the vicious cycle of "the spraying of pesticides, followed by the increase in the pests' resistance to the pesticides, and further spraying of the pesticides" in Yumenoshima in the Tokyo Bay. This game was inspired by this incident. That is, in the game, the stronger the "trap" set by the users, the more the "baboo" evolves.

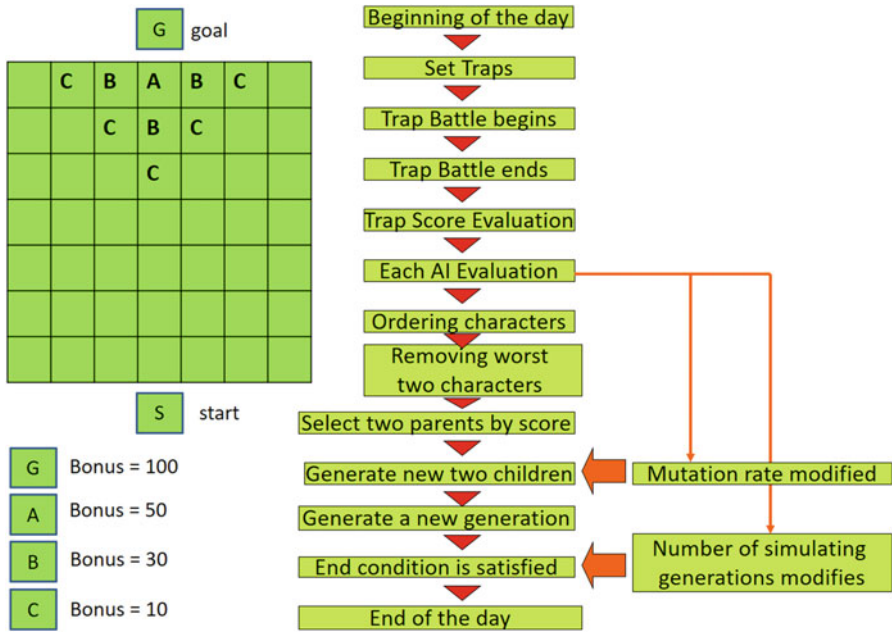
Each character has a parameter column that determines the performance of the character. The parameter column comprises 56 kinds of items, such as physical fitness, endurance, arm strength, leg strength, and resistance to various traps (Morikawa 1999).

Each baboo challenges the traps, and the result is given as a score; baboos with higher scores are selected so that they become parents with high probability based on their superior adaptability and pass their genes to the next generation. Their mutation rate is set to 3% (Fig. 4).

While on the surface it appears that among the 20 baboo characters in the game, each character is challenging the trap only once, in the background, simulations are carried out for all the 20 baboo characters evolving over five generations; this mechanism can only be implemented in a game. This is done to make the users believe in the evolution of the enemy. If the rate of evolution is low, more generations are added, and conversely, if the rate of evolution is high, the number of generational changes are reduced.

Study on Machine Learning at Microsoft Research

In the game industry, the third AI boom took place after 2015, although research on the application of



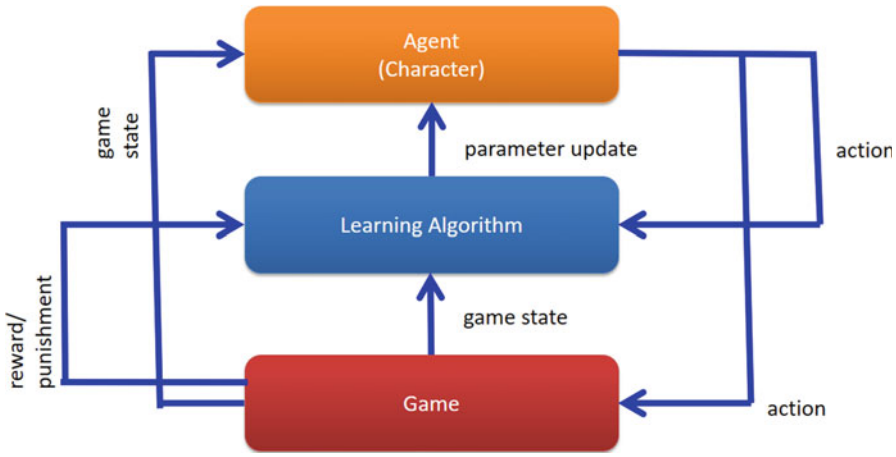
Classical Learning Method in Digital Games, Fig. 4 Genetic algorithm mechanism in "Astronōka"

ML in games has proliferated, Microsoft Research, from as early as 2004, was engaged in research on ML in digital games. The success of this research is exemplified in "Forza Motorsports" and various papers. As mentioned earlier, before 2004, a group in Microsoft Research studied the fighting game "Tao Feng" (Microsoft, Studio Gigante, 2003). They studied the reinforcement learning of characters (Herbrich et al. 2008; Graepel et al. 2004). Reinforcement learning is an algorithm to learn from experience. Instead of any clear teaching signals, rewards are set with respect to the orientation of learning that enable the agent to learn actions from the surrounding environment in accordance with the rewards. Two types of rewards have been used in fighting games. The first is rewarded when an attack hits the opposing character (reducing the opponent's physical strength). In such a reward system, reinforcement is realized through repeatedly learning the skills to use in a particular situation. As a consequence, a character that has undergone reinforced learning through tens of such engagements will become a "strong" character. Conversely, the reward is provided when the character is able to skillfully dodge an attack from the enemy. Consequently, the character after undergoing reinforced learning through tens of such engagements will become a "fleeing" character. This way, a character can be taught through reinforcement learning, and the orientation of such learning is determined by the rewards. In particular, Q-learning, which is an algorithm for reinforcement learning, was used in this study. Q-learning is suitable for continuous reinforcement learning with temporal transitions, and it is frequently applied to learning in digital games.

Machine Learning in Forza Motorsports Series

In Forza Motorsports, a player called "Drivatar" has the ability to learn driving skills and generate ghosts to drive. First, the course in Forza Motorsports is divided into segments. The segments can be straight or hairpin-shaped. An ideal course is set for each such segment. Then, the deviations from these specified courses are measured (Herbrich et al. 2008) (Fig. 5).

Next, to reproduce the deviations as a ghost, they are reverse transformed and reflected in the controller operation to reproduce the previously measured deviations. Instead of forcing the car to follow the externally specified course, it is reduced to a reverse problem, where the car attempts to reproduce the course "just as the user had deviated."



Classical Learning Method in Digital Games, Fig. 5 Reinforcement learning algorithm (Herbrich et al. 2008)

Case-Based Reasoning in Killer Instinct

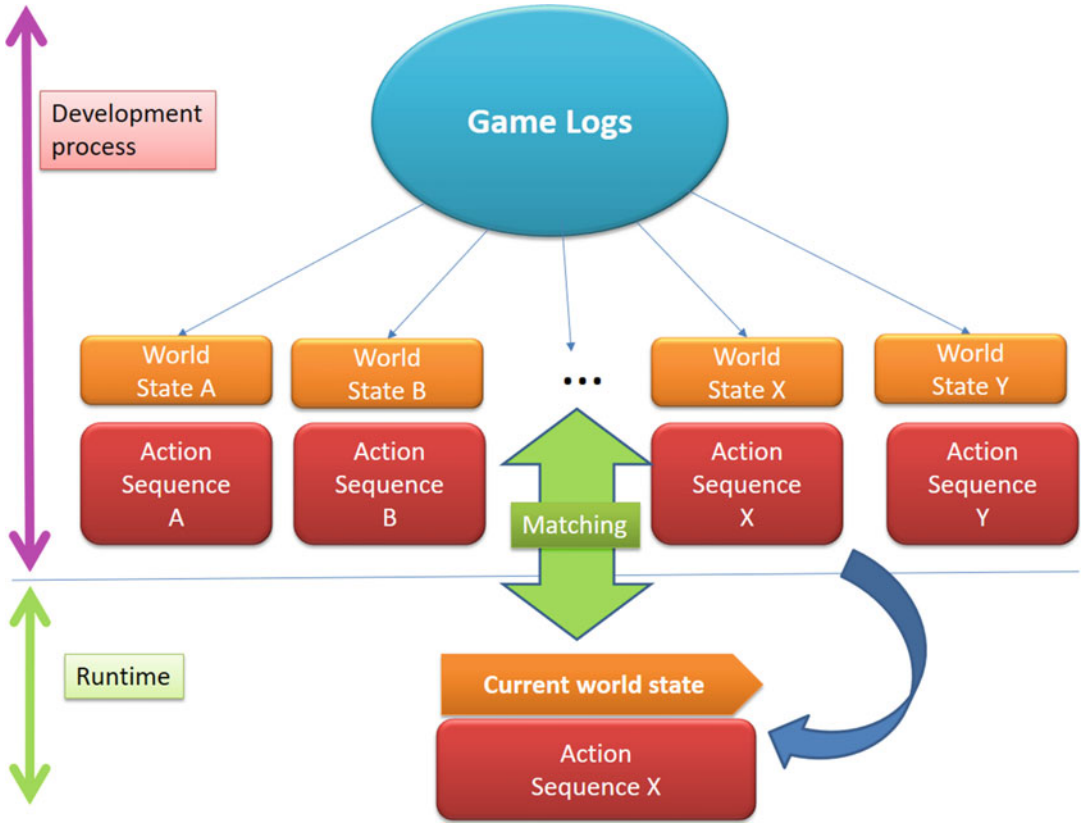
"Case-based reasoning" (CBR) is an algorithm for obtaining a solution to the problem under consideration from the recollections of similar cases in the past. Although a few studies on the application of CBR to digital games have been reported, very few actually adopted them (Aha et al. 2005).

"Killer Instinct" (Rare Ltd., Microsoft Corp., 1994–2016), created "Shadow" that grows through learning the fighting and style of players from past data (Hayles 2015). By accumulating game logs and using the concept of abstract distance, multi-dimensional and large-dimensional data are vectorized into "Game State," and the most effective action corresponding to each such state is extracted. When the game is played, the Shadow searches such data for the action most appropriate for a specific situation (Fig. 6).

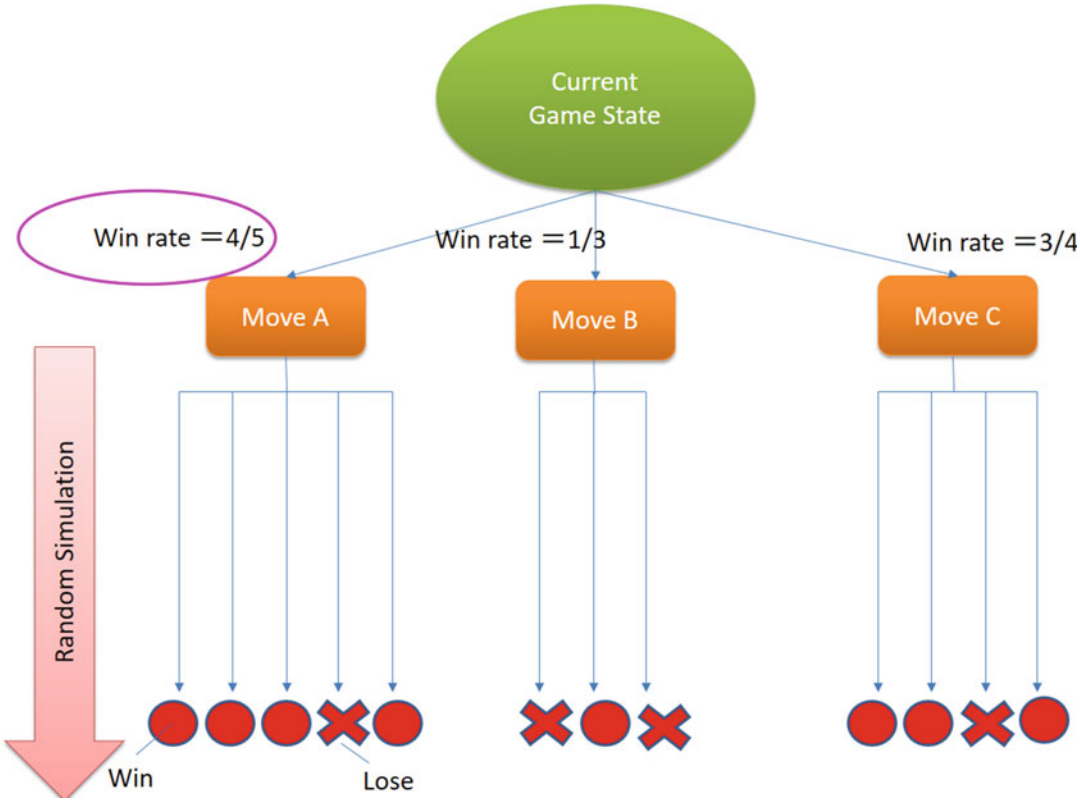
Monte Carlo Tree Search in TOTAL WAR

Monte Carlo Tree Search (MCTS) is a revolutionary and powerful method that was invented for the computer Go program. Simulation is the primary approach in this method. Further, as it requires no evaluation, it is very useful in game development. Hence, many related studies have been conducted on its application to computer games (Fig. 7).

When there are multiple candidate moves, the MCTS algorithm performs random simulation of all possible moves of the game beyond that point and selects one after evaluating the win–loss status of all such moves. Moreover, the number of simulations is increased for promising moves, to generate an index called upper confidence bound (UCB), which is the cornerstone of this algorithm.



Classical Learning Method in Digital Games, Fig. 6 Case-based learning principle



Classical Learning Method in Digital Games, Fig. 7 Monte Carlo Tree Search Method

MCTS has superior applicability to simulation games and has been used for adjustments in the campaign mode (single-user mode including tutorials) in "TOTAL WAR: ROME II" (Creative Assembly, 2013) and "Total War: Attila" (Creative Assembly, 2015) (Champandard 2014). It enables the measurement of the effectiveness of AI strategy by repeating the playouts until the end.

There are three levels in the decision-making by AI when playing "TOTAL WAR":

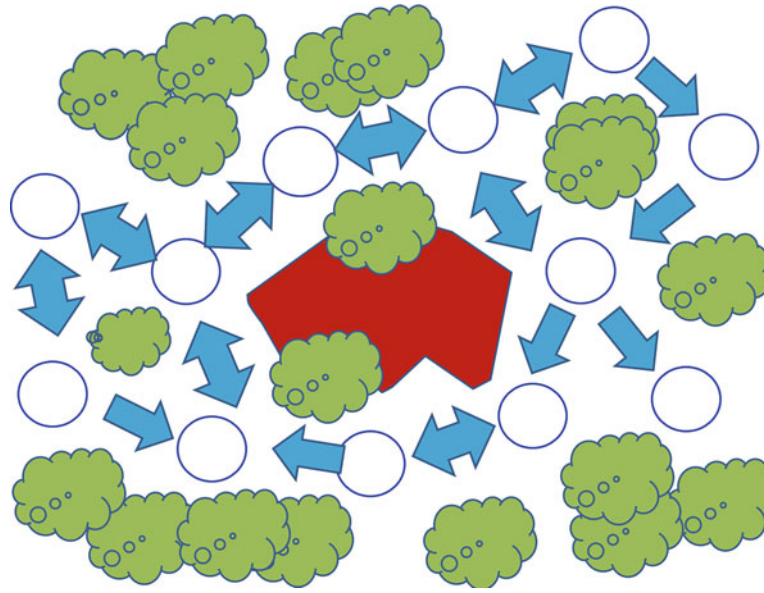
Task creation Set a number of high-level tasks (these do not use MCTS)

Resource allocation Limited resources are allocated to tasks (use MCTS)

Resource assignment MCTS-based decision planner determines the sequence of actions

In this manner, once the AI playing "TOTAL WAR" is developed, it can be made to play many games very rapidly by issuing thousands of commands instantly. Accordingly, it enables the verification of game balance at a very high speed without human intervention.

Moreover, in "Fable Legends" (Lionhead Studios, was not released), MCTS was used to decide the advance of multiple characters (Mountain 2015). Assuming each position as a node, a tree structure that comprised the choices of actions at the respective nodes was considered (Fig. 8).



Classical Learning Method in Digital Games, Fig. 8 Monte Carlo Tree Search in action games

Cross-References

▶ Navigation Artificial Intelligence

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Clicker Game

▶ Incremental Games

Client/Server Gaming Architectures

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Synonyms

Centralized architectures

Definitions

Client/server gaming architecture refers to a typical distributed architecture for the support of networked games. In this architecture, a single node plays the role of the server, i.e., it maintains the game state and communicates with all other nodes (the clients). The server notifies game moves generated by players and computes the game state updates.

Online Gaming Architectures

An online gaming architecture is typically composed of two types of entities: client entities (CEs) and game state server entities (GSSEs). A CE is a client software application that performs input/output with its player and receives/notifies events to the GSSE to which it is connected. Stated simply, a CE acts as a viewport to the game state and passes commands issued by its player to the GSSE. The GSSE computes the advancements of the game state.

Client/Server Architecture

The client/server architecture is the classic solution used in commercial game products, e.g., Quake, Ultima Online, and Minecraft (Briceño et al. 2014). In this case, a single copy of the game state is maintained at the server-side. Each event generated by a CE is sent to the single GSSE that processes the event computing a new game state; then, the GSSE forwards the newly computed game state to all other CEs. During the game, the GSSE controls the generated events' validity.

In this scenario, clients are very simple since they have only to take inputs from the players and render the output state. Consistency is easy to maintain as well as cheating avoidance, because only a single GSSE maintains the game state, and thus a single node is in charge of determining the game state advancements. For this reason, provided that the GSSE is a trusted entity, illegal manipulations of the game state are extremely difficult/easily detected (Ferretti 2008; Mauve et al. 2002). Often, these advantages push game middleware providers to adopt this architectural solution (Bauer et al. 2004).

However, the major drawback of such an approach is that a centralized server could be the bottleneck of the system (Briceño et al. 2014); moreover, the GSSE is a single point of failure. Furthermore, this architecture is not scalable with the number of players (Reis Cecin et al. 2004). Finally, users that experience different network delays, due to their (possibly) different types of connections, are treated unfairly.

Despite these clear drawbacks, this solution is the preferred one in commercial networked games. This is due to several reasons. First is the already mentioned ease of management of the game state and game administration. Second, when the server is maintained by the game distributors, the server acts as an authoritative control node. In the pay-to-play business model, the server permits to control the access to the gaming servers and to reduce (or avoid) the game piracy. Moreover, this allows to profile users and offer additional services related to the game. An example is in-game stores in which gamers can purchase items and services. In the

last years, many online game distributors have switched to a free-to-play business model in which players have access to a significant portion of their content without paying. In this case, the presence of in-game stores is a key part of the business model. Third, today's games allow users with the possibility of connecting to the game using very diverse terminals and modalities of interaction. In this case, a dedicated server can provide each specific user with different output modalities, based on his/her specific needs. An emerging trend in online gaming architectures is multiplayer browser games in which the game is played over the Internet using a web browser. In this case, the client/server approach is now the most appropriate solution even if new technical solutions (e.g., WebRTC) could permit the development of peer-to-peer browser games.

The client/server gaming architecture can be naturally deployed over cloud computing infrastructures (Marzolla et al. 2012). Multiple servers can be hosted in the cloud, which are devoted to handle different gaming sessions. Such an approach increases the scalability of the provided game service. Moreover, in massively multiplayer online games, the game world can simulate a vast area. In these cases, the game state can be partitioned and distributed over multiple servers. Each server handles a specific portion of the game world and interacts with those CEs that are within that area. According to this approach, once a player leaves the area managed by a given server and enters another area (handled by a different server), it must disconnect from the previous server and open a novel connection with the newer server, all that without introducing consistency errors or affecting the gaming experience of the players.

Cross-References

- ▶ Cloud for Gaming
- ▶ Online Gaming Architectures
- ▶ Online Gaming Scalability
- ▶ Peer-to-Peer Gaming

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Clinical Skills

▶ Nursing Education Through Virtual Reality: Bridging the Gap

Clipping

▶ Speedrunning in Video Games

Clothing Brand

▶ Professional Call of Duty Player Matthew "Nadeshot" Haag: An e-Sports Case Study

Cloud for Gaming

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Synonyms

Cloud gaming infrastructure; Gaming as a service (GaaS)

Definition

Cloud for Gaming refers to the use of cloud computing technologies to build large-scale gaming infrastructures, with the goal of improving scalability and responsiveness, improve the user's experience, and enable new business models.

What Is Cloud Computing?

Cloud computing is a service model where the provider offers computation and storage resources to customers on a "pay-as-you-go" basis (Mell and Grance 2011). The essential features of a cloud computing environment are:

On-demand self-service: the ability to provide computing capabilities (e.g., CPU time, network storage) dynamically, as needed, without human intervention.

Broad network access: resources can be accessed through the network by client platforms using standard mechanisms and protocols.

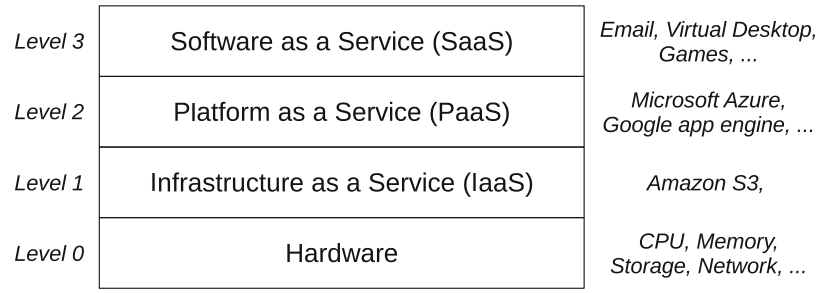
Resource pooling: virtual and physical resources can be pooled and assigned dynamically to consumers, according to their demand, using a multitenant model.

Elasticity: from the customers' point of view, the provider offers unlimited resources that can be purchased in any quantity at any time.

Measured service: cloud resource and service usages are optimized through a pay-per-use business model and are monitored, controlled, and reported transparently to both their customer and provider.

The typical interaction between cloud provider and customer works as follows: the customer connects to a "cloud marketplace" through a Web interface and selects the type and amount of the resources she needs (e.g., some virtual servers with given number of CPU cores, memory, and disk space). The resources are allocated from a large pool that is physically hosted on some big datacenter managed by the cloud provider. Once instantiated, the resources are accessed by the customer through the network. Additional resources can be acquired at a later time, e.g., to cope with an increase of the workload, and released when no longer needed. The customer pays a price that depends on the type and amount of resources requested (e.g., CPU core speed, memory size, disk space) and on the duration of their usage.

The *service model* defines the level of abstraction at which the cloud infrastructure provides service (Fig. 1). In a *Software as a Service* (SaaS) cloud, the system provides application services running in the cloud. "Google Apps" is an example of a widely used SaaS cloud. In contrast, the capabilities provided by a *Platform as a Service* (PaaS) cloud consist of programming languages, tools, and a hosting environment for applications developed by the customer. The difference between the SaaS and PaaS models is that while the user of a SaaS cloud simply utilizes an application that runs in the cloud, the user of a PaaS cloud develops an application that can be executed in the cloud and made available to service customers; the application development is carried out using libraries, APIs, and tools possibly offered by some other company. Examples of PaaS solutions are App Engine by Google, Force.com from Salesforce, Microsoft's Azure, and Amazon's Elastic Beanstalk. Finally, an *Infrastructure as a Service* (IaaS) cloud provides its customers with fundamental computing



Cloud for Gaming, Fig. 1 Cloud service model

capabilities such as processing, storage, and networks where the customer can run arbitrary software, including operating systems and applications. The number of companies offering such kind of services is continually growing, one of the earliest being Amazon with its EC2 platform.

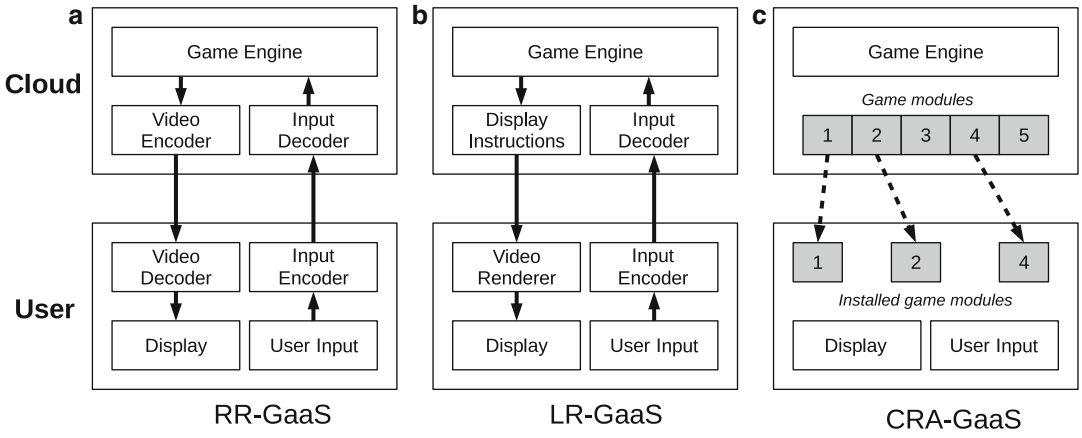
The *deployment model* defines the mode of operation of a cloud infrastructure; these are the private cloud, the community cloud, the public cloud, and the hybrid cloud models. A *private cloud* is operated exclusively for a customer organization; it is not necessarily managed by that organization. In the *community cloud* model, the infrastructure is shared by several organizations and supports a specific community with common concerns (e.g., security requirements, policy enforcement). In the *public cloud* model, the infrastructure is made available to the general public and is owned by an organization selling cloud services. Finally, the *hybrid cloud* model refers to cloud infrastructures constructed out of two or more private, public, or community clouds.

Cloud Computing for Gaming

The gaming industry embraced the cloud computing paradigm by implementing the *Gaming as a Service* (GaaS) model (Cai et al. 2014). Different instances of the GaaS paradigm have been proposed: *remote rendering GaaS*, *local rendering GaaS*, and *cognitive resource allocation GaaS*.

In the *remote rendering* GaaS (RR-GaaS) model, the cloud infrastructure hosts one instance of the game engine for each player (Fig. 2a). An encoder module running on the cloud is responsible for rendering every frame of the game scene and compressing the video stream so that it can be transmitted to the user's terminal where the stream is decoded and displayed. User inputs are acquired from the terminal and sent back to the game engine that takes care of updating the game state accordingly. The advantage of the RR-GaaS model is that the workload on the terminal is greatly reduced, since the computationally demanding step of rendering the game scenes is entirely offloaded to the cloud. This allows complex games to be played on less powerful devices, such as mobile phones or cheap game consoles, that are only required to be capable of decoding the video stream in real time. However, the RR-GaaS model consumes considerable bandwidth to transmit the compressed video stream and may be particularly sensitive to network delays. Examples of RR-GaaS implementations are GamingAnywhere (Huang et al. 2014) and Nvidia GRID™ (http://www.nvidia.com/object/cloud-gaming.html, Accessed on 2015/4/4).

In the *local rendering* GaaS model, the video stream is encoded on the cloud as a sequence of high-level rendering instructions that are streamed to the player terminal (Fig. 2b); the terminal decodes and executes the instructions to draw each frame. Since encoding of each frame as a sequence of drawing instructions is often more space-efficient than compressing the resulting bitmap, the LR-GaaS model may require less network bandwidth than RR-GaaS and therefore eliminate the need for real-time video transmission capability. This comes at the cost of requiring a more powerful terminal with an adequate graphics subsystem.



Cloud for Gaming, Fig. 2 Gaming as a Service models

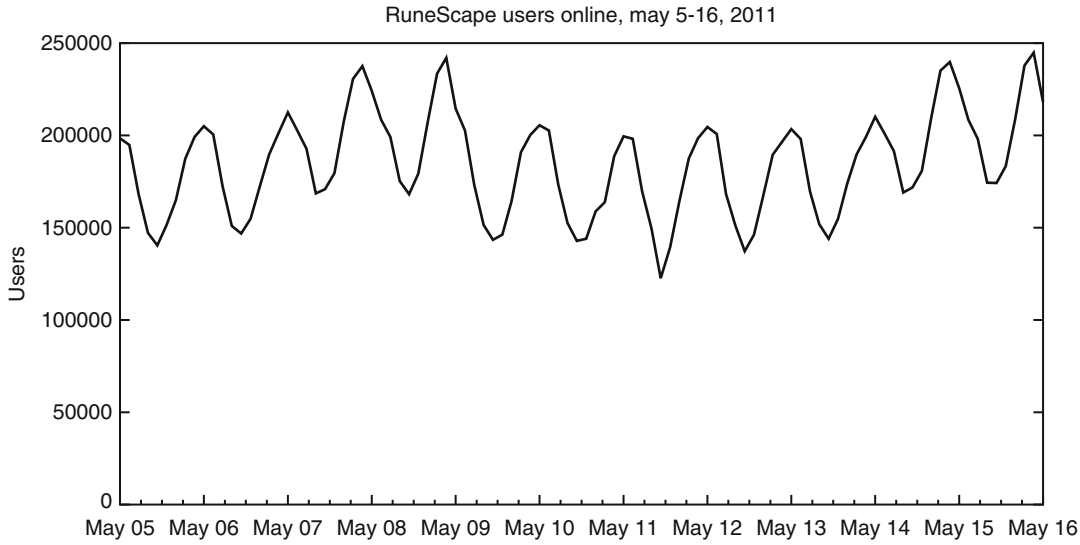
Finally, in the *cognitive resource allocation* GaaS model, the game engine is logically partitioned into a set of modules that can be uploaded and executed at the client side (Fig. 2c). As the game evolves, the terminal receives and executes the appropriate modules and may keep or discard the unused ones. The CRA-GaaS model shifts the computation back to the client terminal, therefore reducing the load on the cloud. However, the client resources are used efficiently, since at any time only the needed components are stored locally. This is a significant advantage if we consider that the data of a complete modern game takes a lot of space for textures, 3D models, sounds, and code modules.

GaaS provides advantages for both game developers and players. The ability to offload some computation on the cloud allows simple terminals such as mobile devices to play complex games. Since the game engine is accessed on demand, flexible business models such as pay-per-play or monthly subscription can be easily implemented. Finally, game operators can scale up and down the amount of cloud resources used by the gaming infrastructure.

The last point is particularly important, especially for the so-called Massively Multiplayer Online Games (MMOGs). Modern MMOGs are large-scale distributed systems serving millions of concurrent users which interact in real time with a large, dynamic virtual world. The number of users playing the game at any given time follows a pattern that originates from the typical daily human activity. As an example, Fig. 3 shows the number of online players of RuneScape (http://www.runescape.com) (Marzolla et al. 2012), a fantasy game where players can travel across a fictional medieval realm. During the observed period, more than 200,000 players are connected to the system at peak hours; this number reduces to about 110,000 players during off-peak hours. Hence, the daily churn (number of players leaving/joining the system during the day) is about 100,000 users. It is evident that static resource provisioning based on the average load results in system overload roughly half the time; provisioning for the worst case results in a massive resource underutilization.

To effectively implement a cloud-based gaming infrastructure, it is necessary to address nontrivial issues related to game state partitioning, responsiveness, synchronization, and security.

Partitioning The key factor for achieving scalability of a GaaS infrastructure is the ability to partition the workload across the cloud resources. This is relatively easy if the workload consists of the execution of independent game instances that can be executed on any available resource, irrespective of where other instances are running. This is the case when the game does not allow different players to interact. Things become complex if the instances are *not* independent, as in the case of a MMOG system where all players interact with the same virtual world. In this case, the game



Cloud for Gaming, Fig. 3 Number of online players of the RuneScape MMOG; the data refers to the period from May 5 to May 16, 2011

engine must maintain a large shared state, allowing the players to "see" the effects of actions performed by the other players operating in the same virtual location.

This is achieved by partitioning the virtual world across multiple zones, each handled by a separate set of cloud resources. Given that communication between resource instances may incur significant delays, it is important that interaction across neighboring zones is minimized. For example, each partition may hold a collection of "islands" such that all interactions happen within the collection, while players can jump from one "island" to another.

Depending on the (virtual) mobility pattern of each player, some areas of the game field may become crowded, while others may become less populated. In order to cope with this variability, each zone controller is physically hosted on resources provided and operated by a cloud infrastructure. The cloud provider is in general a separate entity providing computational and storage resources to the game operator on a pay-as-you-go model. This means that the game operator can request additional servers and/or additional storage space at any time and release them when no longer needed. Thus, the game operator can request more resources when the workload on a zone increases, in order to keep the response time perceived by players below a predefined maximum threshold. When the workload decreases, the game operator can release surplus resources in order to reduce costs.

Synchronization The success of a gaming system is based on having players perceiving the game state as identical and simultaneously evolving on every player participating to a gaming session. If the game state is replicated in different cloud servers, a synchronization algorithm is needed to maintain the consistency of the redundant game state. To this aim, different schemes have been proposed in the literature (Game event synchronization 2006). They mainly differ from classic synchronization algorithms employed by distributed systems in their additional requirement for keeping the computation quick and responsive. To this aim, some schemes relax the requirements for full consistency during the game state computation.

A basic distinction is between conservative and optimistic synchronization. Conservative synchronization approaches allow the processing of game updates only when it is consistency-safe to do so. Lockstep (Fujimoto 1999), time-bucket synchronization (Fujimoto 1999), and

interactivity restoring (Ferretti 2014) are some examples in the literature.

Optimistic synchronization mechanisms process game updates as soon as they receive them, thus increasing the responsiveness of the system. Yet, it is assumed that most updates are received in the correct order and that, in any case, it would be acceptable to recover later from possible inconsistencies.

Examples of optimistic approaches available in the scientific literature are the optimistic bucket synchronization (Diot and Gautier 1999), the combination of local lag and time warp proposed in Mauve et al. (2002), the trailing state synchronization (Cronin et al. 2002), and the improved time warp equipped with the dropping scheme and a correlation-based delivery control approach (Ferretti 2014).

Responsiveness The task of providing a pleasant experience to players becomes challenging when trying to deploy a large-scale and highly interactive online game. Responsiveness means having small delays between the generation of a game update at a given player and the time at which all other players perceive such update. How much such delays must be small depends on the type of online game. Obviously, the shorter the delay, the better. But it is possible to identify a game-specific responsiveness threshold T_r that represents the maximum delay allowable before providing a game update to players. The typical T_r for fast-paced games (e.g., first-person shooter, racing vehicles) is 150–200 ms, but this value can be increased to seconds in slow-paced games (e.g., strategic, role-playing games) (Ferretti 2014; Pantel and Wolf 2002).

A key point is that each player is geographically distributed. Thus, his latency to reach the game server on the cloud is usually different from other players. If a classic client-server approach is employed, it might thus happen that a responsive service is provided to some subset of users, while the other players can perceive a nonresponsive game evolution. This raises another main issue, i.e., fairness provision. This means guaranteeing that all players have the same chance of winning, regardless of their subjective network conditions (Ferretti 2014). To this aim, it should be guaranteed that all players perceive the same and simultaneous game evolution at the same time.

GaaS infrastructures represent an effective tool to provide responsive and fair gaming experiences. Cloud servers can manage the game state evolution in a scalable manner. Multiple server instances can be run in the same datacenter, when needed. Moreover, if the game involves worldwide distributed players, one might think to introduce a federation of cloud servers, geographically distributed, so that each client/player might connect to its nearest server. This could balance the network delays between the player and its server, thus augmenting the fairness level provided by the system. However, when multiple servers are involved, each one with a redundant copy of the game state, synchronization algorithm is needed to maintain game state consistency.

Security and reliability The security issues of GaaS infrastructures have become mainstream after the PlayStation Network outage that, in 2011, has halted the Sony online gaming network for 23 days. The network was shut down after detecting an external intrusion that led to a huge number of accounts being compromised and the exposure of the players' personal information.

From the reliability point of view, large cloud systems provide some level of redundancy to cope with failures, including the use of geographically distributed datacenters, so that catastrophic events do not cause a complete outage. Unfortunately, the GaaS infrastructure may still represent a single point of failure; the PlayStation Network outage is just one example: in that case a security incident prompted the system administrators to temporarily shut down the whole service. Other possibilities must be considered as well: for example, the company operating the GaaS infrastructure may go bankrupt, depriving all players from the game service they might already have paid for.

From the security point of view, GaaS infrastructures are affected by the typical issues of cloud computing (e.g., insider attacks; Zissis and Lekkas 2012) and online gaming (e.g., cheating; Hu and Zambetta 2008). Online games are an appealing target for hacks because players often invest huge amount of time in their character

development, and it is therefore quite easy to monetize game items on the black market. Additionally, individual accounts on online gaming platforms often contain information, such as credit card numbers, that are the typical target of cybercriminals. Details of the avatar of each player can provide information such as sexual preferences (Huh and Williams 2010) that could cause considerable embarrassment if made public.

Cross-References

▶ Virtual World, a Definition Incorporating Distributed Computing and Instances

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Cloud Gaming Infrastructure

▶ Cloud for Gaming

Clustering

▶ Machine Learning for Computer Games

Co-creation

▶ Game Prosumption

Codec

▶ Postproduction in Game Cinematics

Cognitive Disabilities

▶ Making Virtual Reality (VR) Accessible for People with Disabilities

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▶ 2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making

Cognitive Processing

▶ Cognitive Processing of Information Visualization

Cognitive Processing of Information Visualization

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Synonyms

Information visualization

Definition

Information visualization is the use of computer supported, interactive, visual representations of abstract data to amplify cognition (Card et al. 1999).

Introduction

Information visualizations turn raw data into information and enable researchers to gain insight from the data. Understanding how viewers interpret different types of visual information contributes to the creation of effective and intuitive visualizations. This paper introduces the cognitive processing of visualizations from the angles of pre-attentive processing, visual working memory, cognitive load, and sensemaking. The hope is that this will provide readers enough of an understanding of visualization through visual perception and cognition theories and methods. We presented two case studies that illustrated how cognitive theories inform and impact our research.

State of the Art Work

Vision's Constructive Power

Gardner (1983) advocated for a multiple intelligence theory in 1983 that has drawn the attention of researchers due to its premise that each individual difference's intelligence is composed of multiple intelligences. The intelligences are independent and have their own operating systems within the brain. People with higher visual and spatial intelligences respond better to visual cues by storing, manipulating, and recreating visual information. The constructive power of human vision has drawn the attention of researchers for many years. This section reviews the work of Hoffman, Gombrich, and Arnheim in the domain of visual intelligence and discusses how they inform, impact, and relate the creation and viewer interpretation of information visualizations.

Hoffman and Vision's Constructive Power

Hoffman (2000) attempted to explain the complex mental construction process of all sighted individuals. In Visual Intelligence (Hoffman 2000), he introduced sets of universal and specialized rules that govern our perception of line, color, form, depth, and motion. Hoffman's rule of generic views and 10 rules of visual intelligence clearly explain how individuals interpret and construct visual objects. These rules indicate how our mind organizes data and turn data into knowledge. They can be widely applied to visualization design. People have countless interpretations of what they see, but humans prefer to perceive things quickly and efficiently. The generic views rule is that designers should construct a stable view and a constant image. If an object has more salient-part boundaries, humans will see it as a figure because it is more efficient for our

perception to process clearer evidence and a stronger boundary. Havre et al. (2000) were inspired by the perceptual processes of identifying curves and silhouettes, recognizing parts, and grouping them together into objects. They created a novel visualization tool called ThemeRiver that employs the river metaphor to depict thematic variations over time. Temporal thematic changes can be easily recognized because the system uses smooth and continuous curves to bound a theme and distinct colors to differentiate themes.

Moreover, Hoffman (2000) found that if two visual structures have a non-accidental relation, a designer should group and assign them to a common origin. He also stated that if three or more curves intersected at a common point in an image, they should be interpreted as intersecting at a common point in space. These rules can guide the design of movement data through grouping and stack trajectories based on time proximity and visual similarity. Crnovrsanin et al. (2009) plotted trace as distance to the explosion (y-axis) vs. time (x-axis). By applying proximity, audiences can easily depict the entire event a glance and identify different patterns, such as spatial concentration, co-incidence, trends, and divergence. In order to make a powerful design and compelling product, visualization researchers need to integrate these rules and construct what human beings desire to see with little effort.

Gombrich and Constructivist Perception

Gombrich (1977) proposed in Art and Illusion that visual perception is always functioning as a projection of prior experience and imagination, or the so-called constructive. As a constructivist, Gombrich pointed out that artists manipulate the inherited pictorial schemata to directly observe the world, and in turn correct the schemata based on their interaction experience. Gombrich (1977) also pointed out that the ability to recognize objects was the result of perceptual tuning and selection attention. He differentiated looking from seeking, and stated that viewers experience four-step processes of image engagement while looking at images. The four steps include attention (focus), interest (cognitive awareness of the focus), involvement (meaning attached to the awareness), and attitude (feeling resulting from the meaning) (Gombrich 1977). The first step is to be attracted to parts of the image. Then a viewer attaches some meaning to the parts. Thereafter, viewers will normally generate some feeling or attitude towards the image. At this point, looking changes into seeing with a statement of the image. The attitudes, in turn, affect the way viewers perceive the image. The engagement process clearly presents how viewers interact with pictures, and therefore enlightens the visualization design.

Shneiderman (1996) was inspired by Gombrich's schemata and proposed a famous visual information-seeking mantra: Overview first, zoom and filter, then details-on-demand. The mantra has served as a golden rule in visual analytics because it takes human perceptual abilities in current design into consideration. It is very easy for audiences to scan, recognize, and recall images rapidly. Audiences detect changes in size, color, shape, movement, or texture. It is intuitive for audiences to perform tasks like dragging one object to another. Almost all successful visualization design supports the overview, zoom and filter, then details-on-demand. Guo et al. (2014) used dodecagons to visualize GPS data. The system provides an effective overview to show the common patterns. It also allows analysts to filter and examine individual patterns in detail through various interactions.

Arnheim and Gestalt Principles

Arnheim (1969) defined picture perception as the composition of circles, lines, squares, and other forms of graphs into shapes and patterns. The innate laws of the structure are called Gestalt theory. In Art and Visual Perception: A Psychology of the Creative Eye (Arnheim 1974), Arnheim detailed picture-making based on balance, shape, form, growth, space, light, color, movement, dynamic, and expression. Gestalt laws, such as figure/ground, simplicity, completeness, good continuation, and the like were named as fundamental to human perception and visual design.

Visual balance is an innate concept as well as a key principle with which designers convey

messages (Pornstein and Krinsky 1985). Learning visual balance enables designers to create visualizations that "look visually right" (Carpenter and Graham 1971) with respect to color and layout. Arnheim (1974) illustrated the balance concept with a structural net that determined balance. He described that every visual work had nine hotspots and visual elements on the main axes or at the centers that should be in visual balance. Weight and direction led to visual balance. More specifically, the characteristics of visual objects, such as location, size, color, shape, and subject matter, influenced visual balance. In spatiotemporal visualization, it is not an easy task to arrange map elements – legends, scales, borders, areas, place names, and glyphs – into an aesthetically pleasing design. Dent (1999) employed the structural net as a guide for thematic map creation. The research effectively used all spaces and retained a harmonious balance among visual elements.

Arnheim proposed that visual thinking occurred primarily through abstract imagery (Arnheim 1969). Arnheim stressed the importance of reasoning with shapes and identified the nature of abstraction in visual representation. Designers always use visual abstraction to clean up the display and impress observers. When using visual abstraction in information visualization, researchers should keep in mind that the meaning of the raw data sets should be preserved true to their original form. Numerous visual abstraction approaches have emerged in the visualization field. Agrawala and Stolte (2001) presented route maps to depict a path from one location to another. Through specific generalization techniques involving distortion and abstraction, route maps were able to present trajectory in a clear, concise, and convenient form. Lamping et al. (1995) created a novel, hyperbolic geometry approach to visualize large hierarchies. Interaction techniques, such as manipulating focus, using pointer clicks, and interactive dragging, emphasized important actions that viewers tend to focus at the expense of distorting less important information. Humphrey and Adams (2010) employed the General Visualization Abstraction (GVA) algorithm in providing a novel technique for information abstraction, such as selection and grouping. This approach facilitated abstraction by identifying the most relevant information items after assigning an importance value to each item. GVA could be applied to geographic map-based interfaces to support incident management and decision-making. Visual abstraction helps to transfer the meaning of the original data into a slightly different but clearer form. Additionally, visual abstraction also supports the cluttered graphical representation of numerous big data sets by replacing the data with new visual elements corresponding to higher levels of abstraction (Novotny 2004).

Preattentive Processing

Human brains can rapidly and automatically direct attention to information that has the highest salience as well as suppress irrelevant information based on simple computations of an image (Healey and Enns 2012). This is often called preattentive processing and provides the informational basis of attentional selection (Logan 1992). Detection precedes conscious attention. Selection cannot occur until the ensemble coding and feature hierarchy of pre-attentive process is complete.

Many research efforts have tried to address the following central question: which properties of visualizations rapidly attract people? Selective attention usually binds features, such as color, shape, location, and texture, into a perceptual object representation (Wheeler and Treisman 2002). Ware (2012) identified visual properties that are pre-attentively processed in visualization. These are also referred to as pre-attentive attributes that can be perceived in less than 10 ms without conscious effort, and require 200–250 ms for large, multi-element displays. These attributes are grouped into four categories: color (hue and intensity), form (line orientation, line length, line width, line collinearity, size, curvature, spatial grouping, blur, added marks, and numerosity), motion (flicker and direction of motion), and spatial position (2D position, stereoscopic depth, and convex/concave shape based on shading) (Ware 2012). The result, which makes symbols pop out, can be applied to information visualization design.

Five notable theories explain how pre-attentive processing occurs. The feature integration theory proposed a model of how low-level human vision is composed of a set of feature maps that can detect features either in parallel or in serial (Treisman 1991), and a master map of locations that is required to combine featured activities at a common spatial location (Treisman and Gelade 1980). Texton Theory focused on statistical analysis of texture patterns. A group of texture patterns consists of three categories: elongated blobs (e.g., rectangles, ellipses, line segments) with specific properties, such as hue, orientation, and width; terminators (ends of line segments); and crossing line segments (Julesz 1981, 1984). Researchers stated that only a difference in textons or in their density can be detected (Julesz 1981). Instead of supporting the dichotomy of serial and parallel search modes, Duncan and Humphreys (1989) explored two factors that may influence search time in conjunction searches: the number of information items required to identify the target and how easily a target can be distinguished from its distractors. Duncan and Humphreys (1989) assumed that the search ability depends on the type of task and the display conditions. Search time is related to two factors: T-N similarity and N-N similarity (Duncan 1989). T-N similarity refers to the amount of similarity between targets and nontargets that have a positive relationship with search time and a negative relationship with search efficiency. N-N similarity represents the amount of similarity within the nontargets themselves that have a negative relationship with search time and a negative relationship with search efficiency. Guided search theory was proposed by Wolfe (1994). He constructed an activation map for the visual search based on bottom-up and top-down visual information (Wolfe 1994). Users' attention is drawn to the highest hills in the activation map, which generates the largest combination of bottom-up and top-down influences (Healey and Enns 2012). More recently, Boolean Map Theory was presented (Huang and Pashler 2007). Researchers divided the visual search into the two stages of selection and access, and divided the scene into selected elements and excluded elements. This is referred to as a Boolean map. Viewers were able to generate Boolean maps in two ways: by specifying a single value of a feature or applying union and intersection onto two existing maps (Huang and Pashler 2007).

Visual Working Memory

Baddeley (1992) stated that the working memory model consists of a phonological loop that maintains verbal–linguistic information, a visuospatial sketchpad that maintains visual and spatial information, a central executive to control and coordinate the operation of the systems, and an episodic buffer to communicate with long-term memory. Working memory decides which activities to perform, inhibits distracting information, and stores information while accomplishing a complex task (Miyake and Shah 1999). Luck and Vogel (2013) defined visual working memory as the active maintenance of visual information to serve the needs of ongoing tasks. The last 15 years have seen a surge in research on visual working memory that aims to understand its structure, capacity, and the individual variability present in its cognitive functions. There are three essential theoretical issues related to visual working memory: discrete-slot versus shared-resource, visual representation, and visual context.

Visual working memory research has largely focused on identifying the limited capacity of the working memory system and exploring the nature of stored memory representations. The field has recently debated whether the capacity of visual working memory is constrained by a small set of "discrete fixed-precision representations," the discrete-slot model, or by a pool of divisible resources in parallel, the shared-resource model (Luck and Vogel 2013; Huang 2010; Zhang and Luck 2008). Visual working memory allows people to temporarily maintain visual information in their minds for a few seconds after its disappearance (Luck and Vogel 1997). Some researchers proposed that working memory stores a fixed number of high-precision representations when people are faced with a large number of items, and no information is retained about the remaining objects (Luck and Vogel 1997; Pashler 1988; Zhang and Luck 2008). Luck and Vogel

(1997) also stated that it is possible to store both the color and orientation of four items in visual working memory. Some researchers found that both the number of visual objects and visual information load imposed capacity limits on visual working memory up to approximately four or five objects (Alvarez and Cavanagh 2004; Luck and Vogel 1997; Pashler 1988), and six spatial locations represented allocentrically in a spatial configuration (Bor et al. 2001). Thus, the temporary storage of visual information is more related to integrated objects rather than individual features. This statement is also consistent with the selective attention metaphor that visuospatial attention is like the beam of a flashlight. People are unable to split their attention to several locations and are, instead, always paying attention to the most important events while simultaneously filtering out all distractions.

However, other researchers claimed that the visual working memory is able to store imprecise representations of all items, including low-resolution representations of the remaining objects (Bays et al. 2009, 2011; Bays and Husain 2008; Frick 1988; Wilken and Ma 2004). They thought of visual working memory as many low-resolution digital photographs and challenged the concept of working memory by examining the distribution of recall errors across the visual scene. Based on a Bayesian decision model, more visual objects are held in visual working memory and fewer resources are allocated to each object. Thus, in contrast to the discrete slots model, the continuous resource model emphasizes that the storage capacity of the visual working memory is not limited to the number of visual objects. Recent empirical evidence on recurrent neural networks suggests that a discrete item limit is more favorable (Luck and Vogel 2013). Although there is still much ongoing debate regarding the models for resource allocation, there is general agreement that visual working memory has an important object/resolution trade-off: as more items are stored in visual working memory, less fidelity per visual item can be maintained (Brady et al. 2011).

Additionally, what we see depends on where our attention is focused, and our attention is guided by what we store in our memory. Attention and visual working memory are closely connected. The central executive of working memory manages the direction of attention and the supervision of information integration. Moreover, both attention and visual working memory have a limited capacity of visual features that can be detected or maintained. Preattentive processing plays a critical role in which visual properties our eyes are drawn to, and therefore helps people deal with visual and spatial information in working memory.

Cognitive Load

Cognitive load refers to "the total amount of mental activity that the working memory imposes on working memory at an instance in time" (Cooper 1998). Cooper (1998) also stated, "the most important factor that contributes to cognitive load is the number of elements that need to be attended to." Sweller and his colleagues (Chandler and Sweller 1991, 1992; Sweller et al. 1998) identified three sources of cognitive load: intrinsic, extraneous, and germane. The intrinsic cognitive load is determined by the basic characteristics of the information (Sweller 1993). The extraneous cognitive load is imposed by the designer as they organize and display information (Chandler and Sweller 1991, 1992). Designers are always striving to reduce cognitive load and help viewers grasp the underlying information more effectively and efficiently. Finally, the germane cognitive load is the roaming free capacity that uses the extraneous load to build a new, complex schema (Sweller et al. 1998).

Miller (1956) developed our understanding of working memory by using information chunks that could be strung together. He and his followers also believed that working memory had a capacity of between seven and ten chunks at any given time (Merriënboer and Sweller 2005; Miller 1956). In terms of visual working memory, the capacity is limited to approximately four or five visual elements (Alvarez and Cavanagh 2004; Luck and Vogel 1997; Pashler 1988) and six spatial locations where conscious thought transpires (Bor et al. 2001). Generally speaking, visual elements are schemas that can be understood as models that

organize our knowledge. Different people mentally store different numbers of visual objects. Due to the nature of the material, it is almost impossible to change intrinsic cognitive load with design. However, people can control their extraneous cognitive load using design techniques. The level of the extraneous cognitive load may be modified based on how designers present information to users. The germane cognitive load is more so focused on individual self-regulation and concerns schema automation (Paas et al. 2004). Some research posited that the third resource germane cognitive load may have a positive impact on working memory, whereas the intrinsic and extraneous cognitive loads are considered as negative in impact (Sweller et al. 1998). One metric for the evaluation of visualization is to compare the sum of the intrinsic cognitive load and extraneous cognitive load with the working memory capacity. If the additive effect produced by the three resources is less than the working memory capacity, the visualization system involves lower cognitive overload and good usability, which is more likely to be successful. On the contrary, if the sum exceeds the user's working memory capacity, the visualization system has higher cognitive overload and poor usability, which is far less likely to be successful.

Visual working memory has a limited amount of processing power and capacity. Users will get overwhelmed and abandon a visualization task when the amount of information exceeds their visual working memory capacity. The designer must use various design strategies to keep the cognitive load imposed by a user interface to a minimum; therefore, more visual working memory resources are available for activities. Also, cognitive load varies by user. Examples include the involvement required for interaction. For an experienced user, adding interaction may assist them to gain insight from the data. Such interactivity might increase cognitive overload and make the visualization more difficult for the novice user. By reducing extraneous cognitive load with visual analytics techniques, we can minimize the total cognitive load imposed by the visualization interface, which will increase the portion of available working memory to attend to information.

Sensemaking

Sensemaking is the process through which people make trade-offs and construct new knowledge of the world (Weick 1995). These processes include the encoding, retention, and retrieval of information in a temporary workspace or working memory. Sensemaking is constrained by the structure and capacity of working memory; the operation of the knowledge base is constrained by its own nature and architecture (Gilhooly and Logie 2004). Visual analytics is defined as the science of analytical reasoning facilitated by interactive visual interfaces (Thomas and Cook 2005). The field aims to support sensemaking processes and gain insight using an interactive, visual exploration of the data set. However, due to the limited capacity of visual working memory, it is very difficult for people to discover and keep track of all patterns while looking at visualization graphs. Also, inconsistencies between mental models and external representations increase the cognitive overload and thereby further hinder sensemaking outcomes.

There are three phases and loops in the sensemaking process: information foraging, information schematization and problem-solving, and decision-making and action (Ntuen et al. 2010). Information foraging is a cost and benefit assessment of maximizing the rate of gaining valuable information and minimizing the number of consumed resources. Based on the metaphor of an animal foraging for food, information foraging theory helps visualization researchers discover effective ways to represent massive amounts of data and provide effective mechanisms for navigation. Challenges include formalizing contributions, such as identifying trends or outliers of interest, posting explanatory hypotheses, and providing retrieval mechanisms. Information schematization is regarded as an information fusion tool or thinking process that uses new information to explain surprise and update prospective, predictive states of a situation. Decision-making supports situational understanding in which a stimulus is placed into a framework to understand, explain, attribute, extrapolate, and predict a process that leads to situational understanding. Sensemaking deals with seeking, collating, and

interpreting information to support decision-making (Ntuen et al. 2010). Information content is held in active working memory. Sensemaking can be applied to information visualization with the intent to reduce complexity and simplify the volume of data collected in order to create understanding. Visualization can serve to amplify or weaken cognitive ability.

The following section presents two spatial-temporal data visual analytics systems to illustrate how cognitive theories could be applied to the design and development of visualization system.

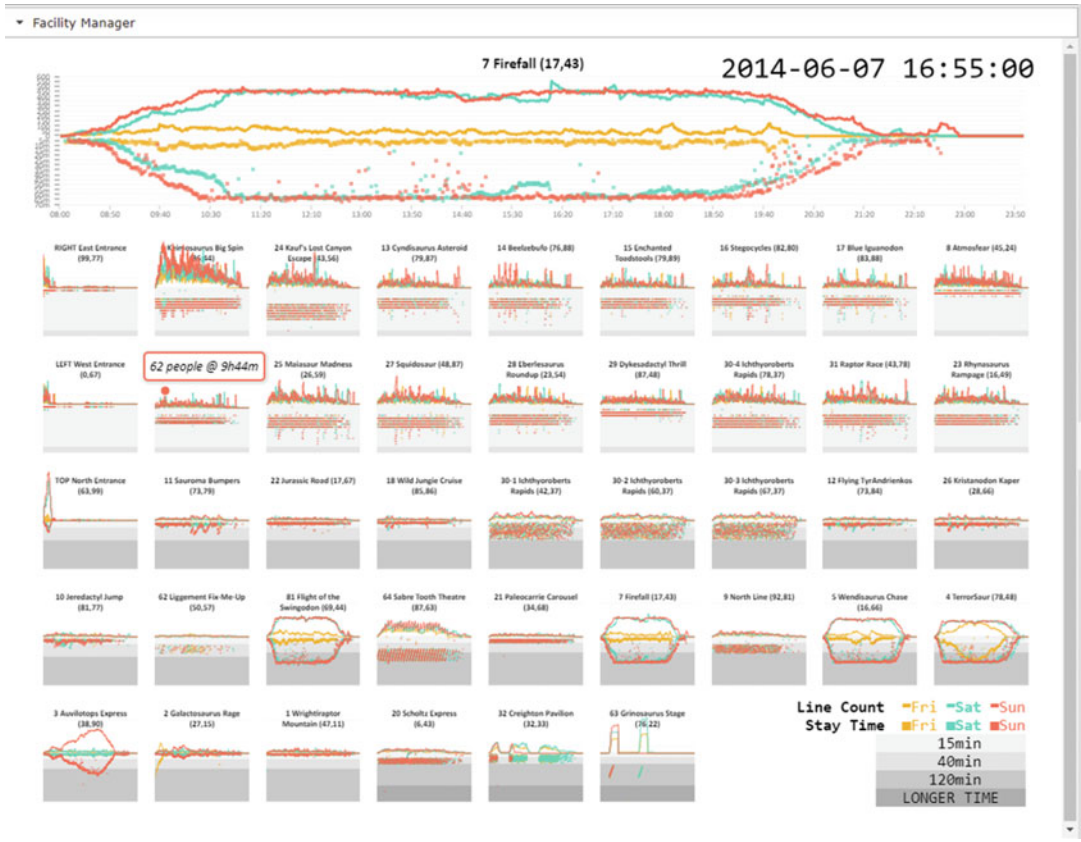
Case Study 1: Vast Challenge 2015 CrowdAnalyzer

CrowdAnalyzer is a system developed from the IEEE Visual Analytics Science and Technology (Vast) challenge 2015 (Wei et al. 2015). With a background that DinoFun World is a typical amusement park, sitting on hundreds of hectares and hosting thousands of visitors every day, a dataset including 3 days' movement tracking information of visitors is provided for researchers to identify the patterns and outliers of attendances and park's activities during those 3 days.

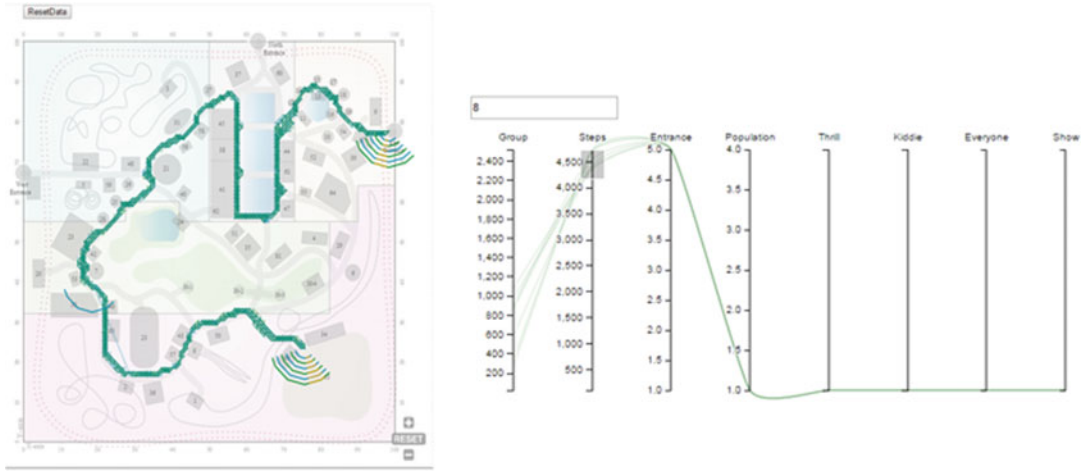
CrowdAnalyzer is designed to visualize visitors' movements, analyze parks' facility status, and identify visitors' group and movement patterns. The system has four parts: facility manager, group hierarchical inspector, enter-leave time group viewer, and map (Fig. 1). Due to the huge amount of data, it is impossible to present the data at once. CrowdAnalyzer allows the viewer to get an overview first and then decide which area of the map they did like to further investigate through zooming in and filtering the details of the data.

The tab "Facility Manager" presents the parks' entertainment facilities' status: the number of people waiting and the estimated waiting time. Multiple line charts are used to present the data. The positive y-axis represents the number of people, the negative y-axis is the waiting time, and the x-axis is the timeline. The colored points on the coordinate show the number of people waiting to take the ride at the corresponding time points. According to Arnheim (1969), people will interpret the composition of different forms of graphs into shapes and patterns. The user will automatically categorize the same color dots into a group. The good continuation between the same colored dots will make them into a line from Gestalt principles of perception (Arnheim 1974). The line depicts the waiting people and the waiting time's change through time, and the distinct colors differentiate the data on different days. In Fig. 1, people will know that the waiting people and time on Friday is much lesser than the weekend.

To reduce users' visual working memory, in CrowdAnalyzer, every visualization has a legend on the corner. Windows are arranged side by side to convenient users' exploration and comparison. Hundreds of thousands of tourists visit the park in 3 days. To reduce users' workload from both perception and memory aspects, it is important to categorize visitors into typical groups. Researchers applied statistical analysis (K-means and EM algorithms) on data criteria (such as visiting date, entering location, and population) to cluster individual tourists into hundreds of small groups. Then visualize these groups using parallel coordinates. The parallel coordinates have eight vertical axes (group ID, walking steps, the number of the entrance, group population, the number of thrill rides, the number of kiddie rides, the number of everyone rides, and the number of shows). The line connecting axes represents a typical visitor group. Users can filter on the parallel coordinates to figure out patterns and outliers. For example, in Fig. 2, the groups that haven't taken any rides but entered the park many times are picked out. The groups' moving trajectories and the key time points are presented on the map. There are two groups of concentric arcs on the map. Each arc represents one group. The arcs with the same radius represent the same group, so we know there are six groups of visitors. As the parallel coordinates show there are only one people in each group, there are six people in total. The start point of the arc represents the visitor's entering time, and the end of the arc represents the visitor's leaving time. We can tell that six people entered and left the park at the same time. The yellow color on the arc represents the duration that



Cognitive Processing of Information Visualization, Fig. 1 Facility manager in CrowdAnalyzer



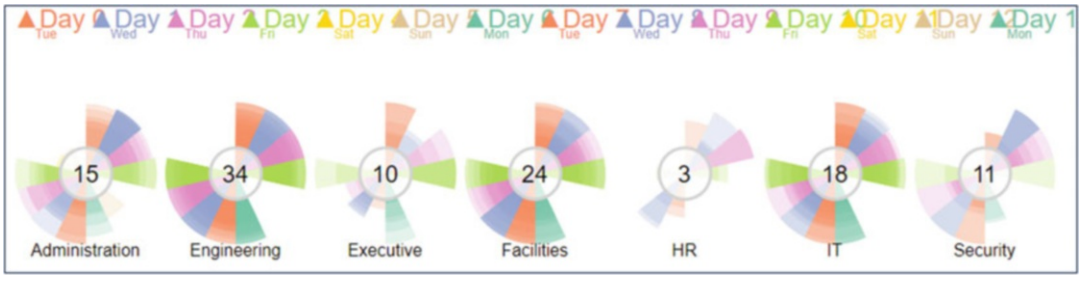
Cognitive Processing of Information Visualization, Fig. 2 Enter-leave time group view and parallel coordinates in CrowdAnalyzer

the visitor stayed at the place on the map. In conclusion, from the trajectories and arcs on the map, the six people arrived and left the park at the same time, shared exactly the same path, took a rest at the entrance before entering the park, then took a rest again at the other entrance of the park. Then, we can reasonably consider these people are not visitors but the park staffs who are responsible for float performances. They performed on a fixed route, repeated the performance five times each day, and took a rest after the performance was done. Through filtering out abnormal data on parallel coordinates and presenting detail information on the map, users are able to observe and understand the characters of different types of visitors.

Case Study 2: Vast Challenge 2016 Metacurve

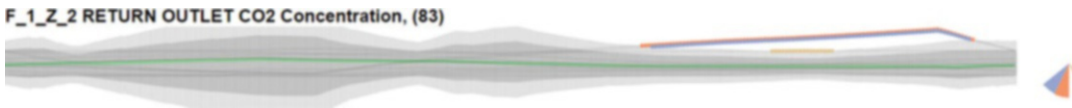
The second system MetaCurve aims to help analysts interpret and analyze periodical time series data using IEEE VAST 2016 mini Challenge 2 dataset. The dataset registered an office building's temperature and HAVC (heating, ventilation, and air conditioning) system status in 2 weeks, and the employees' movements in the building. The first section of MetaCurve is the movement patterns and outliers of employees. Summarized pie charts (Fig. 3) are designed to attract users' attention and guide users to click the pie charts to explore more. In Fig. 3, fourteen arcs make up a pie chart. Color is used to differentiate different arcs, and the black stroke between arcs strengthens the boundary of arcs. The radius of each arc represents the number of outliers of employees' movements. Although in the weekend, employees took breaks and the arcs are not shown, people still have the visual ability to make up the absent part, recognize the pie chart, and further understand the information that pie chart is designed to express. The seven pie charts showing movement anomalies of seven types of employees present that the movements of employees from the administration, engineering, facilities, and IT departments are more flexible than the employees of the executive, HR, and security department.

By clicking on each pie chart, a detailed visualization combining coordinate, color, shade, and shapes are provided (Fig. 4). Human is sensitive to the difference in color, shape, and shade. Different visual factors are adopted to take advantage of human visual perception. The x-axis of the coordinate in Fig. 4 is the timeline. The y-axis is corresponding to the building floors and zones. From the bottom of the y-axis (first-floor zone 1) to the top (third floor zone 7), each proximity zone is presented. As employee's movement data is periodical data, their proximity records are stacked together in the chart. If an employee appeared at a zone less than four times in 2 weeks, a light shade would be marked at the time. If the appearance time is only once, a dot will be marked on the shade. The orange line marked on the zone shows the location of the employee' office. Figure 4 clearly depicts the movement differences between a security people and an administer.



Cognitive Processing of Information Visualization, Fig. 3 Pie charts in MetaCurve

Cognitive Processing of Information Visualization, Fig. 4 The timeline chart showing the movement differences between a security people and an administer



Cognitive Processing of Information Visualization, Fig. 5 Statistical measurements of CO2 concentration in MetaCurve

The building temperature and HVAC data are also periodical data, which is overlaid onto the timeline in MetaCurve. For continuous data, such as CO2 concentration in Fig. 5, after using statistical measurements to compute the median value, variation, and interquartile, the range between the first quartile and the third quartile is plotted using color and considered as a normal data range. The data points located out of the range are considered as major outliers and marked with dots. The color of dots is corresponding to the date.

By using colorful pie charts, MetaCurve firstly attracts users' attention and then provides detailed spatial-temporal information through combining coordinate, color, curve, and shapes.

Conclusion

The information visualization field is a multidisciplinary field and this field still lacks sufficient theoretical foundations that inform design and evaluation. This paper provided an overview of the literature related to the cognition theories of information visualization. It introduced the underlying cognitive knowledge and the basic perception theories central to the development of the ideas in visualization. The two case studies of information visualization show how the basic cognition theories inform and impact the design and development of information visualization. Investigating the cognitive processing of information visualization can provide a useful way for researchers to describe, validate, and understand

the design work. The value of theories in cognition and perception can further defend and secure the information visualization discipline.

Cross-References

- ▶ Multivariate Visualization Using Scatterplots
- ▶ Teaching Computer Graphics by Application

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Cognitive Psychology Applied to User Experience in Video Games

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Synonyms

HCI; Human Factors; Human-Computer Interaction; UX; UX Design

Definition

The user experience (UX) entails a person's perceptions and interactions with a product or software (such as a video game) and the satisfaction and emotions elicited via this interaction. UX overall refers to an overarching discipline focused on evaluation and improvement of users' experience of a given product or software in development.

Cognitive psychology is a discipline dedicated to understanding the human mind via mental processes such as problem solving, language, perception, attention, and memory.

Introduction

The designer Donald Norman popularized the notion of user experience (UX) in the 1990s (Norman et al. 1995). Originating in the fields of human factors and human-computer interaction, UX as a discipline incorporates knowledge and methodologies from behavioral sciences – including cognitive psychology – to evaluate the ease of use and emotions elicited from a product or system. Video game studios have increasingly turned to this relatively new discipline to ensure that the games they develop offer a compelling experience to the targeted players. The inclusion of UX considerations in the design process saves rather than costs a studio money as it allows for more successful game development, contrary to some misconceptions (see Hodent 2015). According to game designer Tracy Fullerton, to design a game is to create an "elusive combination of challenge, competition, and interaction that players just call 'fun'" (Fullerton 2014, p. XIX). However, no objective definition of fun has emerged, nor any detailed parameters to attain it. UX offers a framework to ensure that the experience intended is the one ultimately felt by the target audience. UX representatives use guidelines (heuristics) and methodologies (user research) to anticipate and evaluate how end users interact with a specific game, software, or service and the emotions elicited via this interaction.

Considering the Player's Mind

The user experience of video games happens in the player's mind (see Schell 2008). An important perspective when considering video games' UX is that the game designers and end players may invoke different mental models. Norman described mental models in his seminal book *The Design of Everyday Things* (Norman 1988). According to Norman, a system (such as a video game) is designed and implemented based on the designer's mental model of what the system should entail and how it should function. Players then develop their own mental model of how *they* think the game works through their interactions with it, given their prior knowledge and expectations. The main objective of UX is to ensure that users experience the game (the system image) the way the game developers intended, through players' perception of the game and their interaction with it. The developers have to adjust the vision of the game in development to comply with the limitations of the system (e.g., platform, performance) and the limitations of game production resources (e.g., timeline, workforce). Similarly, the developers must comply with the capabilities and limitations of the human mind to offer a compelling experience to the players. Playing a video game is a learning experience, from discovering the game to mastering its subtleties. Information that the brain processes originates from perceived input that then impacts the memory of a subject. The quality of the processing – and ultimately the quality of the retention – depends highly on the attentional resources applied, which are also dependent on the emotions and motivation felt by the players. Thus, to improve the experience of the players, video game developers must take into account the perception, memory, and attention limitations of the brain, as well as the emotions and motivation felt by the players.

Perception

Perception involves all the mental processes that allow us to sense our environment and construct our own mental representations of it. Thus, these

processes are bottom-up proceeding from sensation to cognition (access to semantics) and also top-down whereby cognition (i.e., previous knowledge, expectation) impacts one's sensations. For example, the save icon (usually symbolized by a floppy disk) is likely meaningless to young children who do not have a mental representation for this object, until they learn what it symbolizes when using a computer. This example illustrates that perception is subjective. It varies depending on the context in which the input is presented and on one's previous knowledge or expectations. Therefore, game players or technology users may understand a specific element differently than what the designer had intended. To ensure that the game menus and signs and feedback will be understood as designed, it is important to assess them with the end users during usability tests whereby, for example, a sample of target users are presented with icons and they have to explain what the icons look like and denote. Ideally, the form (shape) of an icon should correctly inform the players about its function (what it does or how to interact with it).

The signs in a video game refer to all the perceptible cues that either urge the player to execute a specific action or inform the player of a system status. For example, a yellow exclamation mark above a nonplayer character (NPC) encourages the player to interact with that NPC. Other signs, such as a green bar or red hearts, may inform the player of a system status, such as the avatar's health. Game feedback is the reaction of the system to the player's action. For example, an avatar may animate when the player uses the thumbstick or WASD keys. Another example is the ammunition count depleting when the player is shooting. Overall, all possible interactions should have signs and feedback associated with them. These signs and feedback, and the user interface overall, should be perceptible and provide enough clarity to help the player understand the game mechanics. The Gestalt principles provide useful guidelines that should help designers organize the game interface in a way that will be correctly understood by the players (see Johnson 2010, for examples in software design). Gestalt principles account for how the human mind perceives and organizes the environment (Wertheimer 1923). For example, the Gestalt law of proximity describes how elements that are close to one another are interpreted as belonging to the same group. When considering the heads-up display (HUD) of a game, displaying the icons and symbols representing features that are related next to each other enacts this law. Thus, it is what the end players subjectively perceive and understand about the game interface that matters, not the reality of what the developers and designers have implemented.

Memory

Memory allows us to encode, store, and retrieve information and has been seen as comprised of sensory memory, working memory, and long-term memory (Atkinson and Shiffrin 1971; Baddeley 1986). Sensory memory is part of perception and retains sensory information for a very short period of time (such as a fraction of a second) without it being consciously processed. For example, the persistence of vision (e.g., fleeting images) reflects sensory memory, which allows us to perceive a 24-image-per-second display as an uninterrupted animation. Working memory is a short-term component that allows for temporary storage (e.g., a few minutes) and manipulation of a very limited amount of new or already stored information. This system maintains active mental representation necessary to perform a task. For example, performing a mental calculation entails keeping numbers active in the working memory while manipulating them. Working memory requires substantial attentional resources (see the description of "attention" below) and therefore is very limited in duration and capacity. In fact, learning can be hampered and result in cognitive load when work-memory limits are exceeded (Sweller 1994). Long-term memory is a multiple-system component that allows us to store knowledge of events and skills (know-how). Long-term memory has no known limits and is seen as potentially storing information indefinitely although forgetting is possible.

In 1885, the psychologist Hermann Ebbinghaus illustrated with the forgetting curve how memory retention declines exponentially

with time (Ebbinghaus 1885). Retention of information, especially if not engaging emotionally or meaningful, can be very fragile. Some variables have an impact on the strength and quality of the encoding and storage of information, such as the level of processing (the deeper the process the better the retention) and the amount of repetition over time. Not only the brain is prone to memory lapses, but it can also distort memories. Because of these limitations, developers cannot rely too heavily on players' memories. Even if some information has been encoded via tutorials during the onboarding part of the game, it is likely going to fade with time unless used regularly. This is why it is generally a good practice to reduce to a minimum the information that the players have to remember in order to enjoy the game (i.e., mechanics, controls, objectives) and to give frequent reminders, especially since a long time can elapse between two gaming sessions. It is also important to prioritize the information players have to learn and to distribute learning over time. Lastly, the strength of retention can be increased if the players can learn by doing (see Lesgold 2001) in a meaningful context – instead of first reading tutorial texts and then doing. Therefore, it is a better practice to place the players in a situation when they have to execute a new action to accomplish an immediate goal. For example, placing a chest beyond a hole is a meaningful and active way to teach players about jumping and looting mechanics.

Attention

Our senses are continuously assailed by multiple inputs from our environment. Attention entails allocating more cognitive resources to process selected inputs while the others will be ignored (selective attention). The brain's attentional resources being very limited, we do not methodically process all the available information from the environment. Instead, attention works like a spotlight, focusing resources to process and retain particular elements and neglecting the other inputs. For example, when in a loud and crowded cocktail party, one can pay attention to a specific conversation but cannot process all the other conversations at earreach; these are suppressed from conscious attention. Only an attention-grabbing event – such as a sudden loud sound or light flash – can then draw attention away from the current information attended. When attention is divided, for example, when driving while having a conversion over the phone, it requires more cognitive load to process the different information, therefore leading to more fatigue and mistakes. In fact, the brain cannot usually multitask efficiently; either one task or both are performed less efficiently, unless at least one of the tasks is very simple or automatic (such as chewing gum while reading). Similarly, the more demanding a specific task is in terms of cognitive load (e.g., complex mental calculation), the less a subject can allocate mental effort to accomplish another task, even though simple (such as pressing a button when a red light goes off; cf. Kahneman 1973). Subsequently, the more attention is allocated to a task or information, the better it will be retained, therefore learned, as seen in the "Memory" section above. Thus, it is critical to draw the players' attention to the elements that they need to learn. Given that all of our mental processes are using the same limited attentional resources, the developers must mind the cognitive load the game demands from the player, especially during the onboarding of a video game, when the players have a lot of new information to process.

When elements are unattended, they are likely not perceived at all, in a phenomenon called inattentional blindness (Mack and Rock 1998). This phenomenon was best illustrated in the well-known "gorilla" experiment (Simons and Chabris 1999) whereby subjects had to watch a video in which two teams of people were moving around and passing basketballs. One team was wearing black shirts and the other team white shirts. The subjects were asked to count basketball passes made by players of the white team only. In the middle of the video, a person in a black gorilla suit walked into the scene, pauses, and then walked off the scene. The results showed that most subjects, directing their attention into counting the basketball passes from the white team, missed the gorilla although quite prominent in the scene. This study explains why players, when focused on a task, can stay blind to any

other information conveyed at the same time. For instance, if tutorial text information about the health mechanic is displayed while the players are experiencing their first combat, they will likely not process or even perceive that information as all their attention is focused on surviving their first enemy encounter. Therefore, it is preferable to avoid displaying important information when the players are directing their attention to another task.

Emotion and Motivation

According to Norman (2005), "the emotional side of design may be more critical to a product's success than its practical elements" (p. 5). The emotional aspect in video games is frequently addressed through aesthetics, music, or narrative. However, an important aspect of emotional game design has to be considered as well: the "game feel." Game designer Steve Swink (2009) describes game feel as including "feelings of mastery and clumsiness, and the tactile sensation of interacting with virtual objects" (p. 10). Accounting for the game feel involves carefully designing the camera, controls, and characters. For example, if the camera of the game has a very narrow field of view (FOV) it may give players a feeling of claustrophobia, which would be inappropriate for a peaceful exploration game. It could however be appropriate for a horror survival game, depending on the game design intentions.

Players' motivation is another important variable to consider when developing a game. According to Przybylski et al. (2010) "both the appeal and well-being effects of video games are based in their potential to satisfy basic psychological needs" (p. 154). Therefore, a game that satisfies basic psychological needs for competence, autonomy, and relatedness (c.f. Deci and Ryan 1985) will more likely be engaging. Competence entails the players' sense of mastery and feeling of progression towards clear goals (i.e., Nintendo's *Legend of Zelda* series require increasing mastery to progress in the game). Autonomy encompasses offering meaningful choices to the players and opportunities for self-expression (i.e., Mojang's *Minecraft* allows the player to experiment with the game environment in a creative way). Relatedness involves primarily the need to feel connected to others. Relatedness in games is often addressed through multiplayer features allowing players to interact with each other in real time or asynchronously, via cooperative or competitive goals. Sustained motivation and emotional connection both have an impact on the enjoyment of a game. These components also have an impact on the learning experience and the quality of information retention.

Usability and Gameflow, the Two Components of User Experience in Video Games

To ensure a good video game user experience, it is important to consider its usability and gameflow. Making software – such as a video game – usable means "paying attention to human limits in memory, perception, and attention; it also means anticipating likely errors that can be made and being ready for them, and working with the expectations and abilities of those who will use the software" (Isbister and Schaffer 2008, p. 4). Usability is about removing or at least alleviating all the frustrations and confusion the player could experience while playing the game, if they are not intended by design. Broad guidelines – heuristics – can be used to attain usability. Many usability heuristics have been developed, both in web (e.g., Nielsen 1994) and game design (e.g., Desurvire et al. 2004; Laitinen 2008). These heuristics take into account the human brain capabilities and limitations in perception, attention, and memory described earlier. The gameflow component refers to how enjoyable and engaging the video game is. It takes its roots from the notion of flow, described by psychologist Mihaly Csikszentmihalyi as the optimal experience whereby "a person's body or mind is stretched to its limits in a voluntary effort to accomplish something difficult and worthwhile" (Csikszentmihalyi 1990, p. 3). The gameflow component offers a set of criteria, or heuristics, to improve the emotion response and motivation felt by the players, in an

adaptation of the concept of flow into games (Chen 2007; Sweetser and Wyeth 2005). By considering both usability and gameflow heuristics, a UX framework can be developed to provide a useful checklist for game developers (see Hodent 2014a, for an example of a UX framework applied to game design).

Conclusion

To warrant an engaging and enjoyable user experience, game developers need to consider human capabilities and limitations by adopting a UX framework (Hodent 2014b). Such framework is taking into account the limitations of the human brain in perception, attention, and memory. It also considers the emotional response and motivation felt by the players. It can be used during the development of a video game as a checklist to ensure that the usability and gameflow guidelines are respected, therefore increasing the chances of offering a compelling user experience to the targeted audience. A UX framework provides game developers with useful guidance to improve the quality of their game and ensure that their intended design is the one experienced by the target audience.

Cross-References

- ▶ Accessibility of Virtual Reality for Persons with Disabilities
- ▶ Games and the Magic Circle
- ▶ Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay

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Collaborative Engineering

► Collaborative Engineering and Virtual Prototyping Within Virtual Reality

Collaborative Engineering and Virtual Prototyping Within Virtual Reality

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Synonyms

Collaborative engineering; Computer aided design; Computer aided engineering; Prototyping; Virtual reality

Definitions

Computer Aided Design (CAD) and Computer Aided Engineering (CAE) are now benefiting from advantages of virtual reality systems in terms of visual collaboration between engineers, designers, and customers, reducing prototyping costs and minimizing required design and development time.

Introduction

Virtual prototyping is a method in the process of product development. It uses outputs of Computer Aided Design (CAD) and Computer Aided Engineering (CAE) software to validate the design before making a physical prototype. Traditionally, it is done by using one or combination of more than one 3D computer software to generate geometrical shapes and combining them in order to test mechanical motions, functions, and fit. These geometrical shapes represent parts of the project and they could be manipulated by CAE software to simulate the behavior of the part in the real world.

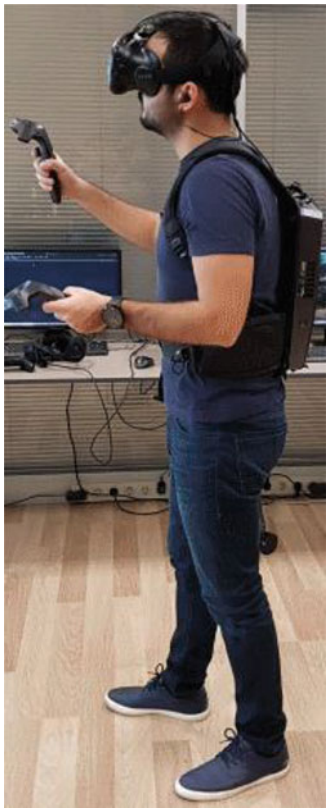
With the introduction of affordable consumer and enterprise head-mounted displays (HMD), engineering groups started to study about implementation of virtual reality technology in order to provide new pathways for engineers, designers, and their customers to experience new products and development processes, without the need of making physical prototypes and mock-ups. Virtual reality can provide any HMD equipped engineer, designer, or customer to have realistic digital prototypes accessible in any place with instant manipulation and assembly/disassembly capabilities.

Background

The product design and development process was used to rely primarily on engineers' experience and judgement in producing an initial concept design. Engineers were using CAD software for designing parts in basic geometrical shapes in a 3D environment; then designed parts were converted to 2D engineering drawings in order to produce them in Computer Numerical Control (CNC) machines without any way to evaluate its performance in advance. The initial prototype was highly unlikely to meet expectations. Engineers usually had to redesign the part multiple times and weaknesses were revealed only in physical testing.

Nowadays, customers are requesting more customized products in high-quality standards

with affordable costs and shorter lead time. This understanding causes a significant increase in product variety and competition in the market. Manufacturers are under pressure to reduce the production time, cost and optimize products to higher standards of performance and reliability. Manufacturers are changing their design and manufacturing processes in order to keep up with the customer demands. Latest progresses revealed that having feedbacks from customers in every step of design and manufacturing process is highly important, even if the product is in the idea phase (Tseng et al. 1998). This approach enabled the utilization of concurrent engineering in design and manufacturing processes. Today, with the help of immersive technologies such as virtual reality and augmented reality, engineers, designers, and customers are constantly able to evaluate the product in functionality, reliability, and aesthetic dimensions and give their feedback in order to change the product design in the design phase without the need of creating physical prototypes (Vosniakos 1998).



Collaborative Engineering and Virtual Prototyping Within Virtual Reality, Fig. 1 HTC Vive usage with a backpack PC

Utilizing Virtual Reality

Virtual reality gives an opportunity to experience any product in any phase with the support of photorealistic visuals, dynamic lights and shadows, simulated physics and dynamics without creating a physical prototype. Also, it is possible to assemble, disassemble, and test mechanical motions of 3D CAD models in virtual environment with the collaboration of multiple participants such as designers, engineers, and customers. This can be done using only an HMD and a computer in any physical space. In order to use it, users need to put the HMD onto their heads and use controllers for manipulating objects as shown in Fig. 1. They also have an opportunity to use real life navigation such as walking and crouching, which give an opportunity to users for walking around the object, looking closer to it from different angles in real time, as if looking to a physical prototype. With the help of built-in or external tracking systems, virtual reality systems can register an arm, hand, and finger movements, which gives the user an opportunity for manipulating, assembling, or disassembling 3D objects in the virtual world with collaboration.

Using an HMD-based virtual reality device is also cost-effective over 3D projection systems such as spherical or CAVE-type virtual environments. These environments require special 3D projectors, projection screens, and a significant physical space. Devices such as 3D projectors are very expensive for utilizing, operating, and maintaining. Also, projection environments need a dedicated space, and it is not possible to use it as a mobile system. Today, HMDs are in the consumer market with affordable prices and they only require a gaming PC and no dedicated space at all. Manufacturers can use HMD-based virtual reality systems for off-site demonstrations or collaborated projects.

In order to use a virtual reality system for collaboration and virtual prototyping, required virtual world must be created with the help of special software. Most of the features for a development of such a virtual prototyping platform are available in game engines supported by the game development industry, which has a value of 25.1 billion USD according to 2010 ESA reports. However, since game engines are developed for making games, some of the specific features are not available and some features do not meet requirements of virtual prototyping standards. As a solution to that problem, some virtual reality and simulation companies started to develop virtual prototyping platforms. One of them is Augmea Immersive Platform (AIP), which is developed by Augmea Simulation Technologies A.S. and it uses the power of state-of-the-art game engine, CryEngine (Altundag et al. 2017). Software products like AIP gives an opportunity to manufacturers for creating virtual worlds in order to use the best features of virtual prototyping technologies in industry standards with cost- and time-effective approach.

Conclusion

Utilization of the virtual reality technology for virtual prototyping gives an important opportunity to manufacturers for experiencing the design, assembling, and disassembling them in order to evaluate the performance of parts or the whole product without the need of creating physical prototypes. Designers and engineers can work together for evaluation and collaborative design, even in different physical locations. They are able to use full body movement, controllers, and sensors in the virtual environment with the photorealistic visuals, dynamic lights, shadows, and simulated physics. HMD-based virtual reality devices are cost-effective over 3D projection systems, and they do not need dedicated installation spaces. With the introduction of affordable HMD devices and special virtual prototyping software, virtual reality can provide any HMD equipped engineer, designer, or customer to have realistic digital prototypes and collaboration space.

Cross-References

▶ Augmented Reality for Maintenance

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Collaborative Environments for Augmented and Virtual Reality Applications

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Synonyms

Shared digital workspaces; Shared environments

Definition

Collaborative environments for augmented and virtual reality applications are virtual environments which can be experienced by more than one user to cooperate in a collaborative task.

Collaborative environments can be designed to be compatible with augmented reality (AR) interfaces, virtual reality (VR) interfaces or both.

Introduction

Human communication and collaboration through digital systems have been the focus of research for more than 30 years. This research field is known as Computer Supported Cooperative Work (CSCW). Though CSCW can greatly benefit from AR and VR, only recently AR and VR have reached technological progress that enables researchers to focus on exploiting these technologies to support collaboration through collaborative environments (CEs). Tech companies such as Microsoft, Vive and Apple are continuously developing new hardware and software to support AR and VR, and among the various application fields, the creation of collaborative systems is widely accepted as one of the most valuable ones.

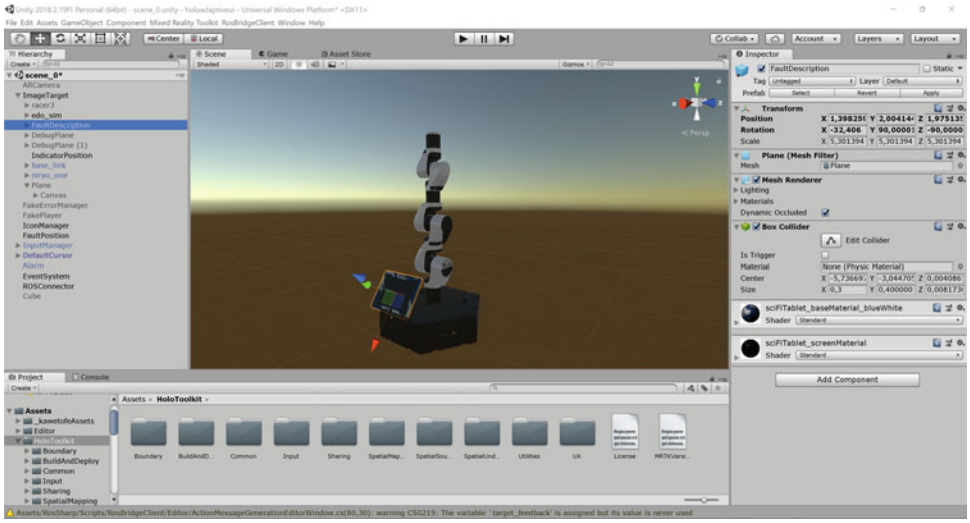
The design of CEs, the technologies adopted to create and experience CEs, and the most common applications' fields are discussed in this chapter.

Technologies

Computer-generated CEs are based on 3D real-time engines, which enable designers to represent the digital contents to be displayed to the users. Unity 3D (Fig. 1) and Unreal Engine are the most known software adopted for designing and implementing virtual environments, whereas many other 3D engines exist, either licensed (e.g., CryEngine) or open source (e.g., Blender). A 3D engine allows designers to create a virtual environment, furnish it with virtual objects, script the objects' behavior, and design and develop the user interaction layer.

Once the virtual environment is available, the second relevant technology necessary to deploy a CE is the physical interface adopted to experience it. Milgram's Reality-Virtuality Continuum (Milgram and Kishino 1994), depicted in Fig. 2, is widely adopted to explain the design space of mixed reality interfaces. Among the physical environment and the virtual one there is a continuum of systems, which merge the physical and virtual world, known as Mixed Reality: depending on the balance of physical and virtual elements, it is possible to further distinguish between augmented reality (AR) and augmented virtuality (AV). An AR system adds virtual elements to a direct or indirect representation of the real world, whereas an AV system adds real elements to a virtual environment.

AR environments are experienced through either video see-through or optical see-through devices (Fig. 3). Video see-through devices record the physical world through a camera and display it combined with the digital contents. These devices can be



Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 1 Unity 3D user interface

Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 2 Milgram's Reality-Virtuality Continuum

Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 3 An example of an AR optical see-through device, the Magic Leap 1 headset. Photo by Bram Van Oost on Unsplash

Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 4 An example of a VR headset, the Oculus Quest 2 produced by Vive. Photo by Remy Gieling on Unsplash

further classified as desktop (e.g., a computer and a webcam) or mobile (e.g., smartphones and tablets).

VR environments are experienced through either traditional displays, which can be classified as mobile or desktop, or immersive virtual reality headsets, which consist of closed helmets with two displays in front of the user's eyes, thus detaching people from the real environment (Fig. 4).

Overall, a CE can be designed to be compatible with both VR and AR devices: whereas VR users will experience a complete virtual world, AR users will see only a subset of virtual elements, which do not inhibit the perception of the reality. This can be obtained by scripting accordingly the behavior of the elements of the virtual environment, depending on what the AR users should see.

	Synchronous (same time)	Asynchronous (different time)
Colocated (same place)	Face to face interactions	Continuous task
Remote (different place)	Remote interactions	Communication & Coordination

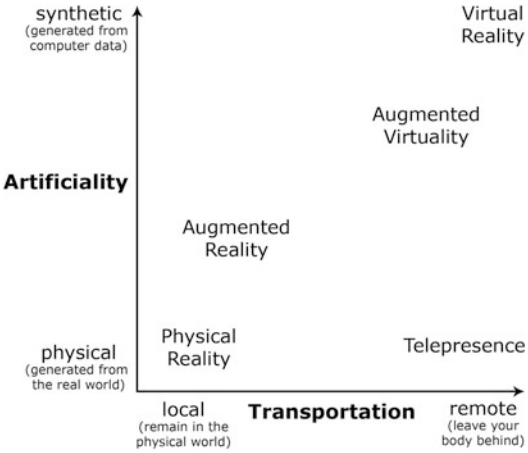
Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 5 CSCW Time-space matrix

Design

The first step in the design of a CE is to define the level of collaboration required or expected for a given task. Since CEs for AR and VR are a specific type of CSCW, the time-space matrix proposed by Johansen (1988) depicted in Fig. 5 provides a clear representation to understand possible typologies and requirements for collaborative activities. The collaboration can be synchronous or asynchronous, whereas the users may interact in the same physical space or they may be located in different places.

Benford et al. (1998) proposed a more complex taxonomy, which combines together the time-space matrix and the reality-virtuality continuum based on three dimensions: artificiality, transportation and spatiality (Fig. 6). Artificiality represents the ratio of virtual content and real content in the collaborative environment, e.g., a completely synthetic world for a VR system or a physical world enriched with digital assets for an AR system.

Transportation defines how much the user is detached from its environment and moved to a remote environment. This feature should not be confused with Artificiality, since the collaboration can either take place in the user environment or in a remote environment through telepresence, and in both cases, AR and VR would not be involved since the Artificiality would be at the bottom level. Spatiality defines how much the collaboration involves a common spatial frame. For example, a collaboration through a chat box would have no spatial reference, the usage of a 2D dashboard would consist of a limited shared spatial frame, whereas a shared virtual environment involves a 3D Cartesian shared spatial frame.



Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 6 Artificiality and transportation dimensions of Benford's taxonomy

The time-space matrix and Benford's taxonomy are valuable tools to understand the different types of collaborative environments. Moreover, it is possible to talk about symmetric collaboration if all the users experience the shared environment by the same level of transportation, spatiality, and artificiality. Examples of the symmetric collaborative environment are two users located in the same space and collaborating through AR, or two users experiencing the same virtual environment through immersive VR. Asymmetric collaboration instead takes place when at least one of the three dimensions of Benford's taxonomy differs from one user to another. An example could be a user who interacts in his/her physical space through an AR device and a remote user

collaborating into a digital twin of the real environment through immersive VR.

Application Fields

CEs are broadly used in several domains and the most important ones are the following: collaborative design, education and training, industry, medical scenarios, tourism, and cultural heritage. Motivation for adopting CEs and examples are introduced and discussed for each one of these research fields in the following sections.

- In the Architecture, Engineering, Construction, and Operation (AECO) area, collaboration and interaction are of primary importance, and architects, engineers, and subcontractors must collaborate closely during each design phase. The project team should make high-quality decisions and innovations by combining the experience and expertise of various professionals. As the complexity of the projects increases, the corresponding amount of data and information increases too, thus potentially generating an uncontrolled working environment. Furthermore, in AECO scenarios, operations and resources are frequently distributed among several actors that may be positioned in different physical locations. Thanks to technological advancements, CEs can effectively exploit VR and AR technologies, thus providing physical embodiment, immersive experiences, and high levels of interaction. Users can obtain an immediate feedback on the design process regardless of the physical location of the involved actors. Blueprints, construction plans, and design sketches can be displayed in the collaborative environments allowing users to provide inputs and changes that are applied on the fly to the virtual assets. Figure 7 shows an example of a collaborative meeting done using AR interfaces.

Representative works are (Lin et al. 2015; Ibayashi et al. 2015). Lin Liu Tsai et al. (2015) proposed a co-located, synchronous AR system to improve discussions related to construction processes. Public data can be visualized using stationary displays whereas private information is directly conveyed to the mobile devices of the involved users. The stationary display consists of a tabletop interface with a dedicated personal computer whereas the mobile devices are represented by Android mobile tablets. Data displayed on the stationary display can be modified via tangible interaction paradigms, that is, the

Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 7 An example of a CEs for AECO seen through AR. Photo by Patrick Schneider on Unsplash

users can manipulate the virtual information by using paper markers tracked with an external camera. The authors compared their system with traditional paper-based approaches, and the main outcomes show a great reduction in the task completion time. Regarding architecture, Ibayashi et al. (2015) presented a synchronous VR system to improve the design phase of architecture sketches. Several users can interact with the same virtual sketches by using two different modalities: a first-person view (by an immersive VR device) to see the fine local details and a top-down view (by a tabletop interface) to have an overview of the entire project. One interesting capability of the proposed system is the so-called "God-like" interaction technique. When the users are touching a specific object of interest on the tabletop interface, the VR users can clearly detect the same object of interest by visualizing a 3D representation of a human hand that pinpoints the objects. Although the system has been described as a co-located scenario, it can be easily extended to a remote one.

- Education and training can greatly benefit from collaborative environments. By presenting educational content in the 3D virtual space, learners can easily and effectively understand structured and complex subjects, especially the ones coming from the mathematical or engineering domains. Furthermore, by exploiting participatory design and gamification techniques, users can improve their knowledge by being directly involved in the learning process. In collaborative environments, two or more users collaborate and learn together to achieve a common goal (Laal 2013). Due to this strong link among learners, users are responsible for their own learning process and that of others (Doymus 2007; Gokhale 1995) (a representative example is shown in Fig. 8).

Some representative works can be found in (Punjabi et al. 2013; Pareto 2012). Punjabi et al. (2013) presented CrowdSMILE, a remote, asynchronous system to effectively handle learning data coming from different sources and tools.

Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 8 Usage of VR headsets for education. Photo by stem.T4L on Unsplash

Contents can be explored using desktop and handheld interfaces, which are used by three different components: (i) *POI Explorer Application*, (ii) *Social Publisher Client Application*, and (iii) *CrowdSMILE Server*. The first component runs on Android mobile devices integrating AR technologies to display learning contents related to the physical environment. The second component allows the users to publish new learning material that will be then explored by the POI Explorer Application. The users can add new location-based learning material by means of handheld and desktop interfaces. The third component provides the main functionalities of the system allowing the exchange of data between the remaining components. The system has been evaluated through a series of user studies showing high levels of usability. Pareto (2012) proposed a co-located, synchronous environment to improve the learnability of mathematical concepts for children with intellectual disabilities. Users can play a series of 2D games to foster reasoning skills and strategic thinking. The games can be experienced using desktop interfaces, interactive whiteboards, and interactive spatial AR systems. The system has been assessed through a series of user studies and the main results show that the gameplay can improve the students' "number-sense" whereas the graphical representation of numbers can greatly assist the students to accomplish mathematical problems they had never been able to solve.

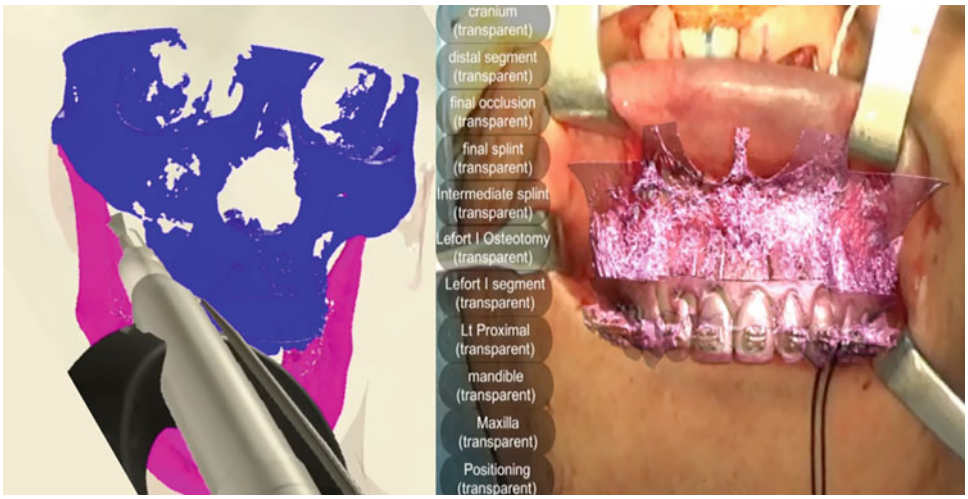
- Industrial scenarios have been also deeply considered and evaluated. CEs have been mainly used for Assembly-Repair-Maintenance (ARM) tasks by leveraging the traditional local-unskilled remote-skilled interaction paradigm. The remote expert tries to help the local unskilled user through a series of procedures and both users interact in the collaborative environment by using a combination of AR and VR devices. In such environments, conveying effective instructions becomes of primary importance, and researchers have devoted great effort to understand which virtual metaphors should be used to improve ARM tasks. Early researches have explored the use of abstract metaphors, such as virtual arrows or generic shapes controlled by the remote user. More recently, the visualization of human body parts by the remote expert has been researched, showing that displaying user's hand gestures in the local user real environment can improve task awareness and decreases cognitive load (Fig. 9). As an example, Huang et al. (2018) evaluated the effectiveness of sharing hand gestures and

Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 9 An example of a virtual environment in an industrial context experienced through a VR headset. Photo by XR Expo on Unsplash

sketches made by a remote user to help a local unskilled operator. The two users interact by using an immersive VR device (remote operator) and a handheld interface (local operator) connected on the same Local Area Network. The main results show that by sharing both hand gestures and sketches the local users can complete the tasks with less time with respect to sharing only hand gestures. The independence of the view has been also deeply investigated. The remote user could visualize the local scene by seeing the environment from the local user perspective (dependent view) or from arbitrary views (independent view), and some researchers have demonstrated the advantages of the independent view with respect to the dependent one (Kim et al. 2018).

- In the medical context, CEs can foster communication between patients and medical specialists. It is expected that medical costs will be increasingly reduced using effective CEs. Nonetheless, several important features, such as latency and tracking accuracy, have not been properly evaluated in this context yet. Similar to the industrial scenarios, by exploiting the visualization of a 3D environment, remote expert medical teams can provide instruction to local unskilled doctors during medical procedures. As an example, Sirilak et al. (Sirilak and Muneesawang 2018) proposed a remote, synchronous AR system to support local doctors during medical operations. The local doctor can visualize by a wearable AR device patients' data captured through dedicated sensors. At the same time, remote specialists can visualize the local scene captured by the cameras of the wearable devices allowing them to collaborate with the local doctors. Finally, the emulation of surgery operations executed in VR can be linked to the data visualization in AR (Fig. 10).

- CEs for tourism and cultural heritage scenarios have been also researched and analyzed. Usually, these systems are used to draw the attention of the users towards points or objects of interest; therefore, it becomes of primary importance providing effective spatial cues to make sure the users are not disoriented or get lost. A typical scenario involves a local AR user who is physically walking through an archaeological site or museum and a remote



Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 10 Left image: a surgical operation can be emulated in an immersive VR environment. Right image: an AR interface can be used to display in real-time patient's data. Images from (Jo et al. 2021)

Collaborative Environments for Augmented and Virtual Reality Applications, Fig. 11 Usage of VR headsets in a cultural heritage context. Photo by Lucrezia Carnelos on Unsplash

guide who can add spatial virtual cues and instructions in the real environment (Fig. 11). Due to their wide adoption, handheld devices are still much more used in these scenarios although head-mounted displays are increasingly researched and studied. Chen Lee Swift et al. (2015) proposed a remote, synchronous system to support cave explorations. Local users can map the real cave creating a virtual reconstruction of the archeological site by using AR wearable devices. Specifically, a local user, wearing a Microsoft HoloLens device, produces a virtual representation of the cave whereas a remote user can either interact with a Skype call or he/she can add virtual annotations by means of a tablet device, thus fostering the cultural experience.

For further information, interested readers may refer to (Ens et al. 2019; de Belen et al. 2019).

Cross-References

- ▶ Augmented Learning Experience for School Education
- ▶ Augmented Reality for Human-Robot Interaction in Industry
- ▶ Augmented Reality for Maintenance
- ▶ Augmented Reality in Image-Guided Surgery
- ▶ Collaborative Engineering and Virtual Prototyping Within Virtual Reality
- ▶ Foundations of Interaction in the Virtual Reality Medium
- ▶ Immersive Visualizations Using Augmented Reality and Virtual Reality
- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Interactive Augmented Reality to Support Education
- ▶ Mixed Reality
- ▶ Spatial Perception in Virtual Environments

- ▶ User-Centered Design and Evaluation Methodology for Virtual Environments
- ▶ Virtual Reality Applications in Education
- ▶ Virtual Reality Game Engines

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Collaborative Problem Solving

- ▶ Challenge-Based Learning in a Serious Global Game

Collaborative Robot Augmented Reality

- ▶ Augmented Reality for Human-Robot Interaction in Industry

Collectable Card Game

- ▶ Hearthstone: A Collectable Card Game Through the Lens of Problem Solving

Collective Intelligence

► Gamification in Crowdsourcing Applications

Collision Detection

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Definition

Collision detection is the process of determining computationally if two or more objects intersect, the time, and the parts of the objects that are involved in the intersection.

Introduction

Collision detection (CD) concerns to determining *if* the intersection between a pair of objects happens, and after a positive answer, to determining *when*, and *where* it happens (Ericson 2005). *If* a pair of objects intersect must give information about the existence of the intersection, whereas *when* they intersect must give temporal information about the time of contact. Finally, *where* the objects intersect must give information about the area of each object that is involved in the intersection.

For applications on robotic and graphic computer areas, it is important to model and simulate the physics of the objects, thus, these areas have used highly CD approaches whereas, specific areas using it include physical-based, surgical, dynamic and cloth simulations, motion planning, molecular modeling, virtual environments, obstacle avoidance, virtual prototyping, virtual assembly, computer animation, among others (Tang et al. 2010; Wong 2011; Zhao et al. 2013; Moll et al. 2014; Du et al. 2015; Wang et al. 2018). Because of the computational complexity, CD is a bottleneck for several applications (Moll et al. 2014), especially, for real-time applications (Pabst et al. 2010; Dinas and Bañón 2015).

Classification of Collision Detection Approaches

CD problem can be classified mainly into four approaches: static, pseudodynamic, dynamic (Basch 1999), and kinetic. However, another division found in the literature is only based on static and dynamic approaches (Ericson 2005). In the static approach, the collision is queried in a particular object position; then, time and usually trajectories are not relevant; the object may change the position randomly, and, consequently, queries are independent (Weller 2013). This approach is used to refine and evaluate the performance time for CD algorithms; besides, the static CD is the first step of a collision detector (Arcila 2008).

Commonly, pseudo-dynamic CD approaches check static interference tests in short intervals of time; they extended the static CD by adding trajectories and times and applying motion (Dinas et al. 2010). In the literature, temporal coherence is the use of preview steps information in a collision detector. It takes advantage of small changes of the objects position to reduce calculations based on the similarity between consecutive motions.

Dynamic CD approaches take advantage of swept volumes to check the collision, and it depends on initial values. There are two types of initial information: the "a posteriori" in which the objects may have a trajectory to navigate through, then the time and the trajectory define the object motion. As a result, the collision is detected after it happens. In contrast, the "a priori" dynamic approach is able to predict the collision before it happens.

Pseudo-dynamic and dynamic approaches deal with oversampling and undersampling problems. Oversampling happens when there is a lot of resource spent into collision evaluations; as a result, there are unnecessary calculations. In contrast, undersampling tests use fewer resources than required to detect collisions; then, some

collisions get lost (Basch 1999). Finally, kinetic approaches take advantage of predicates and certificates functions to determine the CD on time.

A characterization introduced by Zhang et al. (2006) divides CD approaches into discrete, which checks statically collisions between moving objects based on discrete parameter intervals (Pabst et al. 2010; Zhao et al. 2013), and continuous which tries to determine the time of contact (ToC) as exactly as possible (Tang et al. 2010; Wong 2011; Du et al. 2015). Continuous CD is a problem highly explored; the most common techniques are the algebraic solution, the swept volume, the bisection, the Minkowsky sum, the conservative advancement, and the kinetic data structure approaches (Zhang et al. 2006; Tang et al. 2010; Du et al. 2015).

Collision Detection Phases

CD methods are commonly divided into two phases the broad-phase and the narrow-phase. (i) Broad-phase methods determines the pair of objects involved in a potential collision and (ii) narrow-phase methods check exact collision for every pair identified as suspected to be in a collision by the broad-phase (Avril et al. 2014; Wang et al. 2018). Moreover, potential collisions identified in broad-phase are not always collisions; narrow-phase checked the existence of collision.

Broad-phase avoids highly expensive computations for faraway bodies (Weller 2013). An all-pair test or a brute force method calculates exhaustively the collision between each pair of objects.

Narrow-phase checks each pair for intersection between pairs involved selected as potential colliders in the broad-phase (Weller 2013; Avril et al. 2014). Convex objects, spatial partitioning, and bounding volume hierarchies are the most important narrow-phase techniques (Wang et al. 2018). Bounding volume hierarchies are widely used in the literature. The three requirements for bounding volume hierarchies are: (i) each level in the hierarchy represents a tighter fit than its parents, (ii) a set of child nodes in the hierarchy depicts the same part of the object covered by its parent node, and (iii) the bounding volume should fit the original node as tightly as possible with a high degree of accuracy for the original model. However, two opposite criteria that guide the selection of bounding volumes are: they should be as tight as possible, and the intersection test for two of them should be as efficient as possible (Nguyen 2006).

Collision Detection Objects

According to the changes on the objects after the collision, the methods can be classified into two categories: rigid-body models, which do not change after colliding (Tang et al. 2013), and deformable models or soft-bodies, which change after colliding (Tang et al. 2010; He et al. 2015). By exploiting the temporal coherence, models can be deformable along the time, even though they do not collide with others, for instance, animated objects like animals and people, cloth, among others. The collision that involves soft bodies and rigid bodies usually calculates the penetration depth and the area of collision of the objects (Zhao et al. 2013).

Cross-References

▶ Crowd Evacuation Using Simulation Techniques

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Color

► Color: Pixels, Bits, and Bytes

Color Detection

► Color Detection Using Brain Computer Interface

Color Detection Using Brain Computer Interface

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Synonyms

BCI; Brain Computer Interface; Color detection; EEG signal

Definitions

Color plays a critical role in information delivery in this vivid world. Capable of detecting imaginary colors can extend and enhance the current business model as well as the entertainment areas. In order to efficiently determine the imaginary color, essential knowledge of EEG signals, classification of the signals, and how to handle these signals are briefly discussed in this article. BCI applications are mainly divided into three categories: active BCI, reactive BCI, and passive BCI. In these days, most research purpose devices are noninvasive BCIs. EEG signals are commonly considered by four primary bands that carry different information. It is necessary to denoise the captured brainwaves prior to analysis and processing, Linear filter, Bandpass filter, and Independent Component Analysis, three common approaches of denoising are reviewed. Feature extraction and classification methods of brain signals are briefly introduced with former experiment examples. Finally, advantages and adoption preferences of methods are discussed

functionally. This article aims to provide a relatively comprehensive walkthrough of basic knowledge of brain signal processing towards detection of imaginary colors.

Introduction

BCI is generally referred to Brain Computer Interface or Brian Computer Inter-action, which enrich the communication method as well as the information delivery between human-being and machine. Brain signals are captured through BCI devices and then transferred to computer for analysis and processing. BCI devices are mainly divided into two categories: invasive BCI devices are directly implanted into people's brain and medically targeting restoration of fundamental functionality; noninvasive BCI devices are easy to wear and widely used in various applications. Noninvasive BCI devices avoid the surgery risk and are relatively portable, headsets such as Emotiv EPOC+ and Neurosky MindWave are popular in researchers. However, the draw-back of being external device is the relatively poor effectiveness of signal acquirement compared to invasive BCI devices. There are many particularly interesting, entertaining wearables such as the "necomimi" project (the Necomimi Emotion Con-trolled Brainwave Cat Ears Headband), where the headset has two catlike ears that are programmed to wave based on the wearer's emotion that evaluated through the brain signals captured from the brain wave sensor integrated into the headset (Kulkarni and Bairagi 2018).

BCI applications have been deployed into various aspects of world such as home-automation, lie-detection, brain fingerprinting, trust assessment, sleep stage recognition, disease observation, and neurorehabilitation. BCI applications could be macroscopically divided into three main types that differ in the primary characteristics of BCI-interactive models in various applications. Interaction and design models are hence differentiated in numerous researches in the BCI field.

Active BCI: An active BCI application produces its final output from brain activity which is directly consciously controlled by the user such as using mental command, thinking to control hands, and execute actions. Such type of brain activity is independent from external events to control a BCI-application.

Reactive BCI: A reactive BCI application produces its final output from brain activity arising in reaction to external stimuli such as viewing pictures or particular objects. Such type of brain activity is indirectly modulated or reacted by non-subjective consciousness of user to control a BCI-application.

Passive BCI: A passive BCI application produces its outputs by analyzing arbitrary brain activity without specific events for enriching a human-computer interaction with implicit information that user may not aware from the subjective consciousness such as the degree of engagement and relaxing status.

Color has an important role in digital society to present additional information to contents that needs emphasizing and have specific intentions. People coming from different backgrounds and countries could have various understanding on particular colors but commons can be observed. Three primary colors, red, green, and blue are usually applied in color-related researches. These three colors are deemed as the ideal primaries for additive color mixing with the lighting sources (Rossing and Chiaverina 1999). Red associates with energy, danger, strength, power, determination and passion, desire, and love. Green denotes the nature which usually symbolizes growth, harmony, freshness, and passing. Blue is the color of the sky and sea and commonly associated with depth and stability as well as safety. Color detection models are mostly categorized into reactive BCI applications as most applications require participants to be stimulated by a number of colors in order to achieve initial calibrations before the actual usages. Capability of recognizing colors through brain signals could enable researchers to understand deeper and further flexibilities available to developers.

Methods

EEG Overview

Noninvasive Brain Computer Interfaces are usually based on the Electroencephalography (EEG), the electrophysiological monitoring approach to record electrical activity, the communications happened between brain neurons inside human's brain. Extensive researches undergoing in medication and science have the root from Liverpool in 1875, a physician practicing, Richard Caton who demonstrated the presence of electrical currents in the brain (Caton 1875); the first EEG recording of human is achieved by the German physiologist and psychiatrist Hans Berger who afterwards extended the research and invented the electroencephalogram which is described as one of the most outstanding advancement in the history of clinical neurology (Haas 2003).

Unlike invasive EEG devices that directly planted into the brain to monitor brain activities along with a great resolution, noninvasive EEG devices need external auxiliary tools to monitor the brain. Electrodes are introduced in noninvasive EEG devices to equip on the scalp: vertically beginning from the direction of nasion, sunken part of the nose (between eyes, above the bridge of the nose) to inion, the prominent bone at the back of the head; and horizontally from the left ear lobe to the right (Oude 2007).

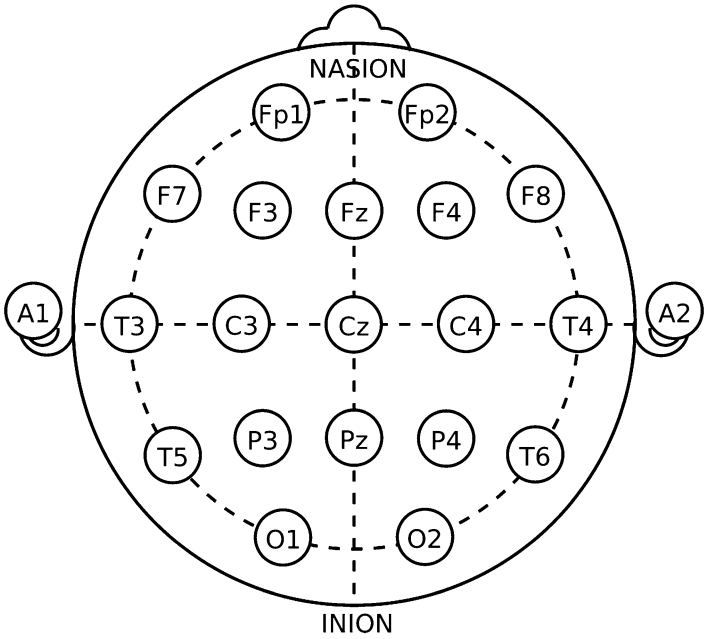
The operation that an electrode captures the electrical activity in brain is called an EEG channel that typical EEG systems have only a few channels available to use. More electrodes denote a clear signal that can be observed from the brain activities. EEG devices are usually equipped up to 256 channels and electrode placement on the head has a formal standard, namely, the International 10/20 system that usually shortened to 10/20 system. The 10/20 system is the standard electrode location method to acquire EEG data and is utilized by most of current databases (Soutar 2014).

The standard placement system, the 10/20 system, suggests the definition of exact position of electrode placement and assignment of symbols that denotes particular electrodes to access particular part of brainwaves that can be monitored from various part of the brain. It defines the placement of electrodes that should be adhered to the calculated distance between nasion and inion for a particular person. The separation of electrode placement is normally defined by particular EEG device depending on the number of electrodes available. In general, a 10% or 20% of the reference distance is utilized, and in circumstances that a greater granularity (resolution in other words) is required, the placement distance of electrodes are further shrink to 10% (Chong et al. 2007).

Usually a greater granularity demands more electrodes to be set up into the cluster that separated on the scalp. A typical prototype of 10/20 placement system is shown in Fig. 1. The nomenclature of electrodes that placed by the 10/20 placement system has particular rules that corresponds to identifications of area or regions of brain that electrodes is reading from such as: Frontalpolar (Fp), Frontal (F), Temporal (T), Occipital (O), and Central (C) (Chong et al. 2007). Specific rules are applied on the numbering measure of electrode placements: even numbers are assigned to the electrode places on the right side of the head and odd numbers are assigned to the left side. Each EEG channel presents different type of information of brain activities; sophisticated analysis of multiple channels is always necessary in order to achieve higher accuracy of classification of brain signals.

EEG Bands

There are many bands available to carry different part of information of brain-waves and the analysis of a particular band may differ depending on the researcher's final goal (Rasheed and Marini 2015). Conventional bands such as delta (< 4 Hz), theta (4–7 Hz), alpha (8–12 Hz), and beta (13–40 Hz) are usually considered as the primary frequency ranges. In the regards of the EEG captured data, the EEG is usually discussed in terms of rhythmic activity (the rhythm) and transients (the fluctuation of amplitude). Cerebral signals observed in the noninvasive EEG devices always state in the frequency range of 1–20 Hz where out of range usually denotes a nonstandard recording technique or it is deemed as artifactual. General



Color Detection Using Brain Computer Interface,
Fig. 1 Electrodes placement (Sjölie 2011)

observations of brainwaves are categorized in below.

Delta (<4 Hz): Delta waves were originally introduced in 1936 by Gray Walter, an English physiologist who acquired very slow and high-voltage potentials that were slower than formerly described wave patterns from the involved area of a patient who was undergoing neurosurgery for a malignant tumor (Marcuse et al. 2015). The characteristic of delta band aims at the highest in amplitude and has the slowest waves. It is usually found frontally in adults in slow-wave sleep and posteriorly in children. As the rule, delta waves are absent in wakeful adults, and in contrary, presence of delta waves during wakefulness implies cerebral dysfunction (Marcuse et al. 2015). Furthermore, delta waves are usually associated with the deepest levels of relaxation and restorative, healing sleep, in other words, adequate production of delta waves enhances the immune system, natural healing and restorative deep sleep (Abhang et al. 2016).

Theta (4–7 Hz): Theta rhythms are generally observed in the frontocentral areas of the brain in young children and are related to drowsiness or heightened emotion states (Scher 2018). Drowsiness arousal can produce theta waves that are observable in older children and adults as well as during meditation. Excess theta waves always de-note a number of clinical conditions, such as epilepsy, or abnormal activity of adults such as focal disturbance (Scher 2018). Additionally, theta waves are usually associated with relaxation, meditation, and creation states.

Alpha (8–12 Hz): The first recording of human EEG waves by Hans Berger is in the alpha range. It is observed in the occipital cortex, the posterior areas of both side of the head (Baars and Gage 2013). Higher amplitude always shows on the dominant side. Alpha waves usually relate to motor activities such as eye movements. Particularly, closing eyes with comfortableness raises the alpha waves and attenuates with eye opening and mental concentration (Bazanova and Vernon 2014). The alpha waves are also subject to age dynamics as the alpha rhythms in healthy subjects reduces associated with age in the interval from 7 to 80 years in terms of power which reaches the highest values around 20 years of age and slowly declines (Kropotov 2016).

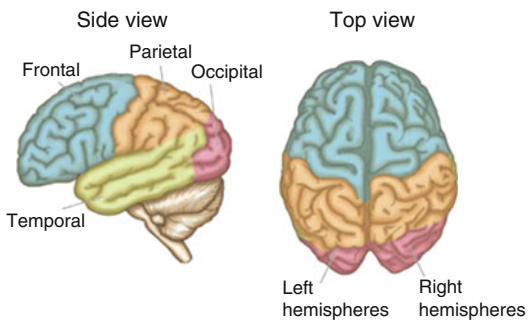
Beta (13–40 Hz): Beta waves are observable with increased possibility in frontal or central

regions of brains compared to posterior areas of the cortex (Kropotov 2010). Beta waves are high-frequency and low-amplitude brain waves in awaken sate and are produced associated with logical and conscious thinking, where production of adequate beta waves enhances concentration (Abhang et al. 2016). Active concentration, busy, active thinking leads to a lower amplitude beta wave, the beta one waves, the low beta waves (12–15 Hz); Mid-range beta waves are described as beta two waves associated with improved performance and anxiety; High beta waves are described as beta three waves associated with significant anxiety, paranoia, and high arousal (Ab-hang et al. 2016).

Brain Lobes and Functions

EEG signals are captured from various positions of the brain. It is critical to understand the brain functions of different cerebral cortices that each of which has important roles to composite the consciousness. The cerebrum dominates the most spaces of the human brain associated with complex brain functions among cogitations and activities. The cerebral cortex is divided into four lobes and two hemispheres which are shown in the Fig. 2.

Frontal Lobe: Frontal lobe is commonly considered as a synonym to the executive functions, utilizing the capacity of the frontal lobes to administrate and improve other cognitive processes more efficient through attention, to inhibit basic response in approaching a complex objective, abstraction and other mechanisms (Pressman and Rosen 2015). In actual, frontal lobes composite of a number of regions that participate various brain processes such as attention, memory, executive functions, insight and self-monitoring, language, and social and emotional functions (Pressman and Rosen 2015). Furthermore, common sense has theoretically different perceptions to the executive functions, are fundamentally classified as the abilities to retain and process objects not physically placed in the surrounding environment (Goldman-Rakic 1996). However, the functional organization of frontal cortex is still controversial where the primary theory proposes that frontal lobes are organized correspondingly to rostrocaudal axis to participate in the hierarchical cognitive control (Badre and Nee 2017). In summary, frontal lobe is functioning in cognition, problem solving and reasoning; development of motor skills; participation in speech; Impulse control; spontaneity; regulation of emotions; regulation of sexual urges; and planning (Abhang et al. 2016).



Color Detection Using Brain Computer Interface, Fig. 2 Brain lobes and hemispheres (Bermúdez 2014)

Parietal Lobe: Parietal lobe is commonly described with correlation to the sensory processing in the brain. It occupies approximately 20% of the cerebral cortex and is categorized into two primary regions, the somatosensory cortex and the posterior region of the parietal cortex which engages in various cognitive operations, especially involved in representations of spatial subjects (Behrmann and Shomstein 2009). Goldberg (2001) described five primary functions: the fundamental analysis of somatic sensation (such as touch, the limb positions, temperature perception); space measurements utilizing sensory modalities; the specification of spatial objects for the motor system; generation of attention; and the analysis of visual motions. In summary, parietal lobe is functioning in sensing pain, pressure, and touch; regulation and process of traditional five senses: vision, audition, gustation, olfaction, and somatosensation; movement and visual orientation; speech; visual perception and recognition; and cognition and process of intelligence (Abhang et al. 2016).

Occipital Lobe: The occipital lobe holds responsibility for visions primarily and is situated posteriorly to both the parietal and temporal lobes.

It is the smallest of the four lobes and it occupies approximately 12% of brain cortex; visual sensations are produced from the occipital lobe through direct electrical stimulations and damage to the occipital lobe can influence visions in different degrees depending on the location damaged and severity of the damage (Galetta 2017). Most of the knowledge of structural organization and processing mechanism of occipital lobe comes from the studies of macaque's occipital lobe which shares a certain degree of similarity with humans. In addition to the spatial specification of visual objects that are maintained in the occipital lobe, visual attributes such as local shape, motion, color, and depth are also extracted and organized (Braddick 2001). In summary, occipital lobe is functioning in visualspatial handling; movement, and color recognition (Abhang et al. 2016).

Temporal Lobe: Temporal lobe associates with perception and recognition, is the region where sound is processed, which regulates the auditory language and speech comprehensions (Baars and Gage 2013). Along with the frontal lobe, the temporal lobe functions significantly in humans, indicating the anatomical relationship of two areas towards acoustic, intelligence, and memory (Bellack and Hersen 1998). In summary, temporal lobe is functioning in management of long-term memories and handles new information, formation of visual and verbal memories, and interpretation of olfaction and audition (Abhang et al. 2016).

Pre-processing of Brainwaves

Captured brainwaves always contain further noises than the useful information. Pre-processing is usually necessary for clearing the noise, reduce the noise ratio of raw EEG signals as the captured raw signals are generally contaminated with irrelevant activities such as eye blinking and physically micro movements. Such activities are called artifacts, which can cause accuracy and efficiency issues in the system. During the recording and amplification period, main's electrical impulse, minor physical movements such as eye blinking or muscle movements and artifacts could interfere the captured data (Rasheed and Marini 2015). Artifacts can also be yielded by the problematic EEG equipment or the external interferences, such as radio waves and mobile phones. Pre-processing methods are commonly required prior to processing and analysis of the recordings. In the former experiment conducted with color detections, a number of methods were utilized to remove artifacts: visual inspection, linear filter, bandpass filter, and independent component analysis (ICA). For event-related potentials (ERP), applying visual inspection along with linear filter or band-pass filter at specific frequency can remove skin potentials at low-frequency bands and muscle and electrical noises at high-frequency bands. Visual inspection is usually necessary to manually remove undesirable segments of brain signals in a trial as the recordings may contain further instructions other than the valuable data, the potentials in recordings with color stimuli. In advanced environment, ICA is significant in removal of artifactual components such as muscle activity, eye blinks, and electrical noises (Delorme et al. 2007). Applying various methods to reduce artifacts could improve the rate of successful classifications, such as Phillips et al. (2015) applied Joint Approximate Diagonalization of Eigenmatrices (JADE) algorithm as the ICA and the classification accuracy shows an approximate 5% improvement over the 20 trials conducted during the experiment.

Feature Extraction

Feature extraction is to extract the adequate feature that is valuable in each single trial. Extensive ways are available to select different features, such as the simplest, calculating the peak in power spectrum, and calculating the mean of a set of trials. Abuhashish et al. (2014) concluded a number of common features are extracted: the value of the EEG signals largeness, band powers, power spectral density ideals, autoregressive and adaptive autoregressive parameters, time-frequency features, and inverse model-based features. Yu and Sim (2016) conducted an experiment that classifies the brainwaves captured during the simulation released by the specially made visual stimulator that manually created using an Arduino board and a couple of LEDs. They extracted N2 (N200, the negative-going

wave that peaks 200–350 ms after stimulus (Folstein and Van Petten 2008)), P3 (P300, occurs when people react to stimuli and surfaces as a positive deflection in voltage with a delay between stimulus and reaction ranging from 250 ms to 500 ms (Polich 2007)), and N4 (N400, the normal brain reactions to meaningful stimuli such as visual and auditory stimuli (Kutas and Federmeier (2000)) of ERP data and achieved classification rates ranging from 35.76% to 87.11%. Aclo et al. (2016) conducted similar experiments utilizing an LED screen monitor doing color stimuli, and Kurtosis was found to be the most significant feature in alpha and beta bands for classification of colors.

Classification

Numerous classification algorithms are available to deploy in different scenarios, such as Support Vector Machine (SVM), Artificial Neural Network (ANN), Multi-player Perceptron (MLP), Naïve Bayes (NB), k-Nearest Neighbor (k-NN), and K-fold Cross Validation. SVM and ANN are the common approaches adopted in researches related to classification of imaginary colors and are briefed in below:

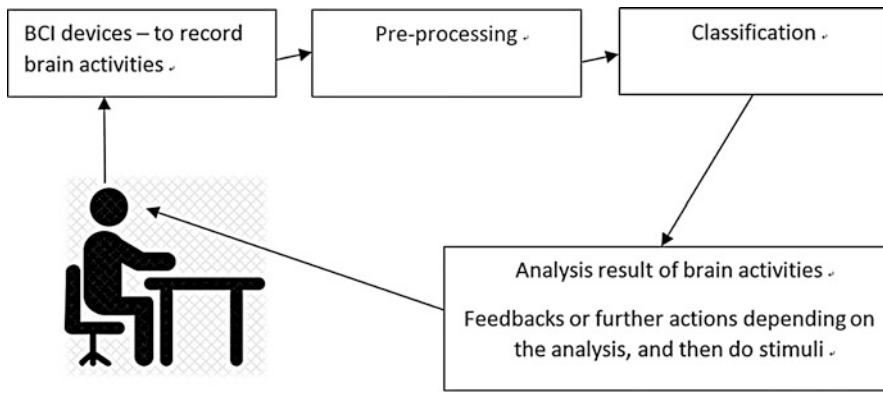
Support Vector Machine (SVM): SVM was introduced in the late 1990s and has been adopted in many engineering-related applications (Gholami and Fakhari 2017). SVM is one of the machine learning, non-probabilistic approach utilizing a linear classifier to categories data into two types and has an overall good performance (Peter et al. 2019).

Artificial Neural Network (ANN): ANN is the computational technique, one of the machine-learning approaches trying to learn the behavior of the brain signals. In analogy, ANN utilizes a large set of computational units, the artificial neurons to simulate brain neurons.

Classification Performance: Classification rate can also be influenced by different combination of selected channels. Selecting one or a few appropriate channels can improve efficiency and performance of the application. Such as Yu and Sim (2016) found that channel T7 and F4 are robust electrodes to classify color imaginations and Aprilianty and Purwanegara (2016) found that F3 and F4 channels are having a better classification rate. Additionally, Yu and Sim (2016) found that applying ANN without LDA can bring an approximate 10% improvement in the classification rate.

A Typical BCI Research Model

A simple, typical BCI application model is described in the Fig. 3. Most of the stimuli researches share commons in basic modelling of the application and can differ based on the final purpose. This model can be applied in the color stimuli experiments, and the devices utilized to present colors can be selected from a large group of different categories, such as the simplest one, computer monitors or some specifically made


BCI devices – to record brain activities
Pre-processing
Classification
Analysis result of brain activities
Feedbacks or further actions depending on the analysis, and then do stimuli

Color Detection Using Brain Computer Interface, Fig. 3 A simple, typical BCI application model

LED devices to represent various colors, achieved in Yu and Sim (2016)'s research. Researchers have the initiative to select particular colors that can be represented by different devices. According to the specifications designed, the final results of different researches could show a certain degree of deviation when the preciseness is critical.

In the color stimuli experiments, a number of participants will be asked to re-main quiet and comfortable before starting the EEG recording sessions. Generally, the device represents a particular color for a few seconds and the brainwaves of participant will be captured and recorded by the BCI devices during each session. The recording sessions will then be pre-processed before apply further analysis and actions. After filtering, denoising, and feature extraction, all recording sessions will be converted into small pieces. These small pieces will then be analyzed and classified into a number of different classes. Based on the analysis and classification result, further actions can be taken and different stimuli scenario can be used to expand the recording library. Usually, a larger library of recording sessions with various scenarios will increase the accuracy and value of the final results.

Discussion

There are numerous feasible approaches to implement the theoretical prescription described in the method section into working solutions, such as BCILab and EEGLab (Delorme and Makeig 2004), two available Matlab applications that greatly simplified the data analysis of brain signals with graphical interfaces. Regarding preprocessing of brainwaves, although ICA can achieve a better result of removing noises in the trials comparing to applying linear filter or bandpass filter, the draw-back is the performance issue as it takes more computational power to produce the processed trial. In the applications that require responsiveness and are designed for portable devices with limited processing power will prone to utilize the other two methods to denoise the signals. In the feature selection part, the experiments con-ducted by former researchers are limited and there are potentials to explore new features. Finally, both of SVM and ANN are commonly adopted techniques, have the same concept using linear learning model for pattern recognition, and the main difference is the way nonlinear data is classified (Ren 2012). Even though some studies suggest SVM has a better performance than ANN, the average accuracy achieved is around 80% and the accuracy decreases dramatically when the training trials are imbalanced.

Color classification can be used in various scenarios of world. For example, in the enhancement of the existing selling models, customers could simply think to get the right color of a desired clothes or items. It can certainly improve the efficiency of shopping as well as reduce the pressure caused on shop assistants during the peak hours. However, BCI devices are still relatively complicated to be equipped and prone to be influenced by the interferences such as radio waves. The cost of device maintenance will also be increased and new technical positions are possibly critical to be fulfilled. Capability of determining the colors imagined can be also used in BCI games to map further actions that cannot be performed by human in the real world such as flying. In the case of mapping a single color to a single action in the game, the traditional gaming can be flawlessly shifted over to the BCI gaming where a higher level of concentration and reaction of gamer could lead to a better result. Furthermore, the research conducted by Abuhashish (2015) also proposed the same idea of eliminating conventional models of interaction between human and computer graphics by analyzing the brain signals to map emotions into the virtual world. Particularly, Abuhashish et al. (2015) constructed the models of mapping human emotions with virtual 3D characters by utilizing Higuchi algorithm to extract human emotions and then to synchronize with in-screen characters.

Conclusion

This article provided a relatively comprehensive overview on the basics of BCI, EEG, and brain functions and a number of feasible approaches of pre-process, extract, and classification in order to

detect imaginary colors. Various terms used in neuroscience are explained and some fundamental knowledge of dealing with brain is briefly introduced. A number of signal pre-processing methods: linear filter, bandpass filter, and ICA and classification methods: SVM and ANN are briefly discussed. Examples of how selling and gaming models can be benefitted with capability of determining imagined colors are finally introduced.

Cross-References

- Augmented Learning Experience for School Education
- Augmented Reality for Human-Robot Interaction in Industry
- Augmented Reality for Maintenance

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Color Primaries

► Color: Pixels, Bits, and Bytes

Color: Pixels, Bits, and Bytes

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C

Synonyms

Bit; Byte; Color; Color primaries; File format; Pixel; RGB

Definitions

Color (in computing) is represented by three values: red, green, and blue which are often also referred to as RGB.

Pixel is the basic, smallest and square-shaped element of a digital image.

Bit is a binary value and the basic unit of computational data.

Byte is the smallest unit of digital information in computational processing and storage.

File format is the structure with specifications on how the information to be organized and displayed.

Pixel and Path

The rapid development of computing and imaging encourages digital creations. Creative software can be largely divided into two types: one for image manipulation and the other for image fabrication.

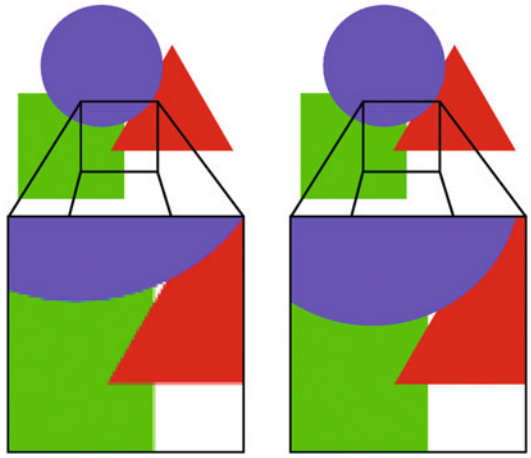
Image manipulation refers to the changing or enhancing the appearance of existing images. Those images are often regarded as raster images with pixels as their basic composition. Image fabrication is oriented for generating original illustrations. The approach is more often vector-based, in which lines and shapes are represented by equations. The basic unit of vector images is called path.

One significant distinction between raster and vector images is the fineness or smoothness in terms of image quality when the magnification

reaches a certain level (see Fig. 1). The quality of vector images is not constrained by scale.

Another distinction is the requirement of processing and storage capacities. Raster images tend to take up much more space than vector images.

Although vector images are more efficient, both in fidelity and space, than raster images, there is still a dominance on the use of raster images. This can be explained by the imaging resources, including software compatibility and file formats. Imaging devices render raster images, which include also photographs (see Fig. 2), and, thus, correspondingly majority of the file formats support raster images.

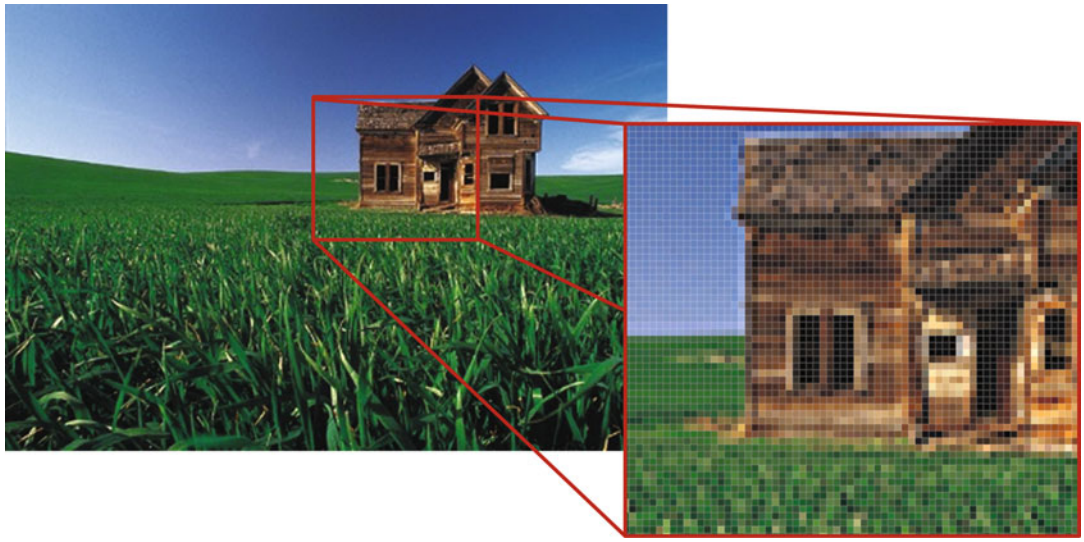


Color: Pixels, Bits, and Bytes, Fig. 1 Demonstrating the appearance of a raster image (top left) with a vector image (top right) at certain magnifying level (bottom)

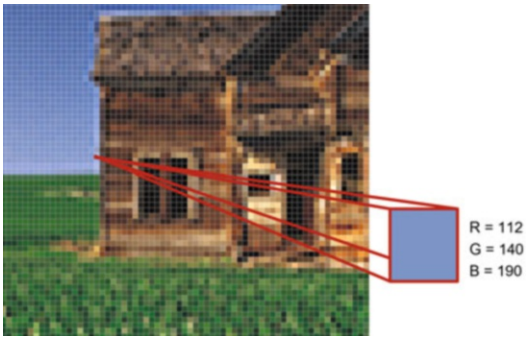
Pixel and RGB

Computer adopts the binary system, 2^x, to process information, and its basic unit is called bit. With the binary system, a bit can be only one of the two values: 0 or 1. That said, two bits (2^2) allow four possible conditions: [00], [01], [10], and [11]. Since the first condition is always regarded as 0, two bits represent numbers between 0 and 3.

As of today, majority of computers are 8-bit (2^8) devices, and thus they can offer 256 conditions ranging from 0 to 255. These conditions allow fine grayscale tonal variations for images. Color images are typically represented by 24-bit with 8-bit per each of the red (R), green (G), and blue (B) primaries. That said, a typical computer is capable to display images with approximately 16.7 million unique colors (Fig. 3).



Color: Pixels, Bits, and Bytes, Fig. 2 The basic unit of a raster image is pixel. A raster image consists of an array of pixels. This example image has a total of 1,100 (width) by 741 (height) pixels. These numbers also represent the image size



Color: Pixels, Bits, and Bytes, Fig. 3 Each pixel has a color that is defined by the red (R), green (G), and blue (B) values

Pixel and Byte

Image file size determines how much computing storage space a file is required. The basic unit of any file size is byte (B). There are also units such as kilobyte (KB), megabyte (MB), gigabyte (GB), and terabyte (TB) to indicate the larger file sizes. See Table 1.

Every 8-bit, which is 256 values, occupies one byte of computing storage space. Therefore, simply one RGB color pixel will require three bytes of computing storage space. Image file size varies, but it is not uncommon to see color image files of several megabytes.

Pixel and File Format

Practically, for websites and apps, several megabytes for each color image could take up significant time to load or download. To allow better efficiency, there are several file formats for users to opt for depending on the intended applications.

Some commonly used file formats for raster images are TIFF (.tiff or .tif), JPEG (.jpeg or .jpg.), and GIF (.gif). TIFF is often recommended for images that require high quality and raw data being preserved. JPEG can compress images by removing certain selected data of the file. It is a popular alternative to TIFF files, especially since it has the flexibility to allow different levels (e.g., 5% or 20%) of data removal. This provides an advantage for images that contain significant saturated colors and smooth gradations, such as sceneries and portraits. For graphical images, GIF file format is preferable since it stores only 8-bit per pixel. That said, a maximum of 256 unique colors which are seen to be sufficient for simple graphics, for instance, logos, graphs, and charts.

Color: Pixels, Bits, and Bytes, Table 1 File sizes – their units and conversions

1,024 bytes (B)	= 1 kilobyte (KB)
1,024 kilobytes (KB)	= 1 kilobyte (MB)
1,024 megabytes (MB)	= 1 gigabyte (GB)
1,024 gigabytes (GB)	= 1 terabyte (TB)

A note to the approach of JPEG file format on reducing file size by removing data is its understanding on the characteristics of pixels in images and the limitations of the human eye. In particular, some pixel values are more common than others, and neighboring pixels have similar colors. Also, very importantly, the fact that small color changes are perceived less accurately by the human eye than small changes in brightness. Thus, the selection of data that to remain and to remove is prioritized by minimum perceptual differences between the original and compressed images.

Cross-References

▶ Teaching Computer Graphics by Application

Further Readings

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Comic Arts

▶ Comic Arts in Games, Asset Production, and Rendering

Comic Arts in Games, Asset Production, and Rendering

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Synonyms

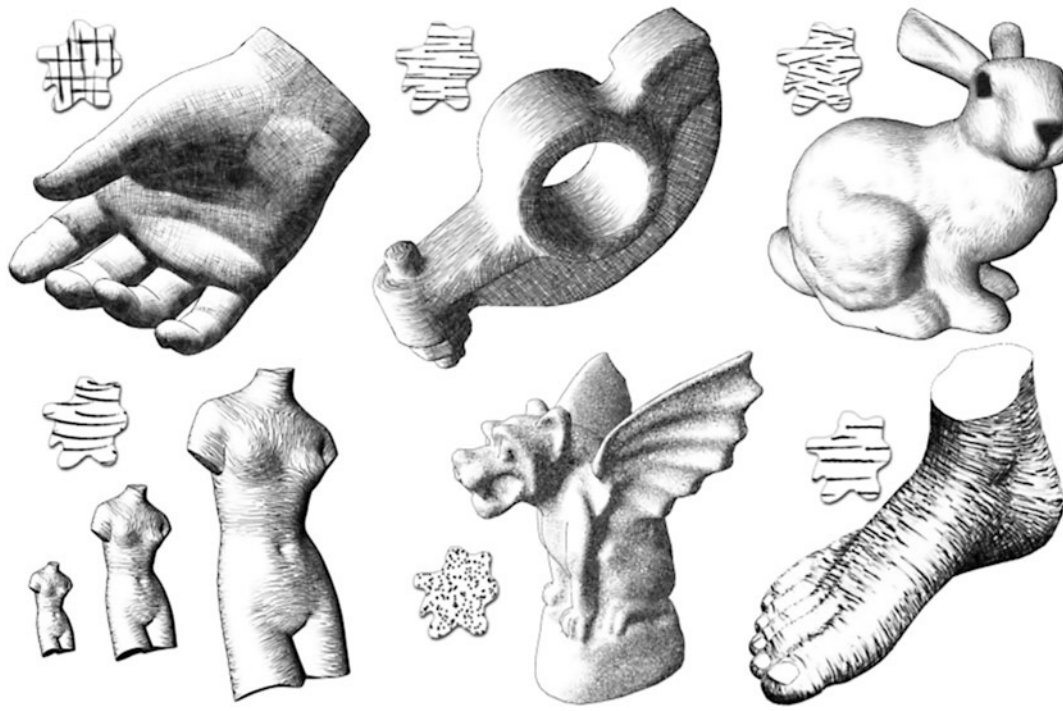
Comic arts; Non-photorealistic rendering; NPR

Definition

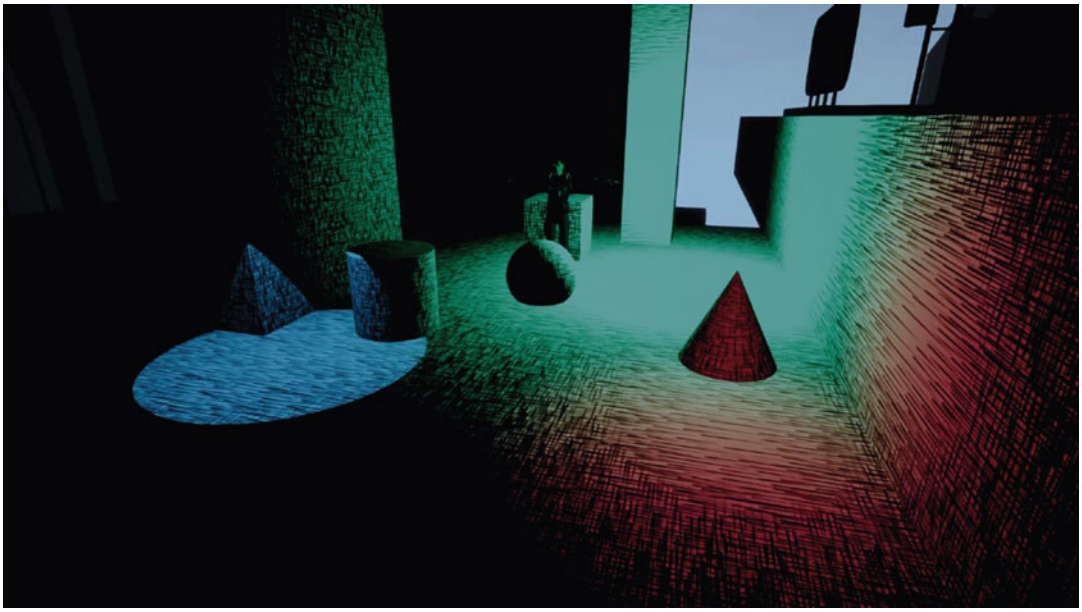
Non-photorealistic rendering (NPR) is a topic under computer graphics trying to achieve some level of stylization in 3D with the use of geometry, lighting, shading, and special effects. Authors are specializing in recreating the aesthetics of comic arts in video games via implementing the research already done in the area and also adding new research topics.

Introduction

Comic art stylization characteristics include toon shading, outlines, line art, hatching, and inner lines. The study of authors started with a literature review and implementing some of the real-time-related works to unreal engine. Unreal engine has been chosen mainly for its rendering quality, and



Comic Arts in Games, Asset Production, and Rendering, Fig. 1 Organic objects samples from the original paper (Praun et al. 2001) with tonal art maps



Comic Arts in Games, Asset Production, and Rendering, Fig. 2 Sample scene in unreal engine with flat surfaces

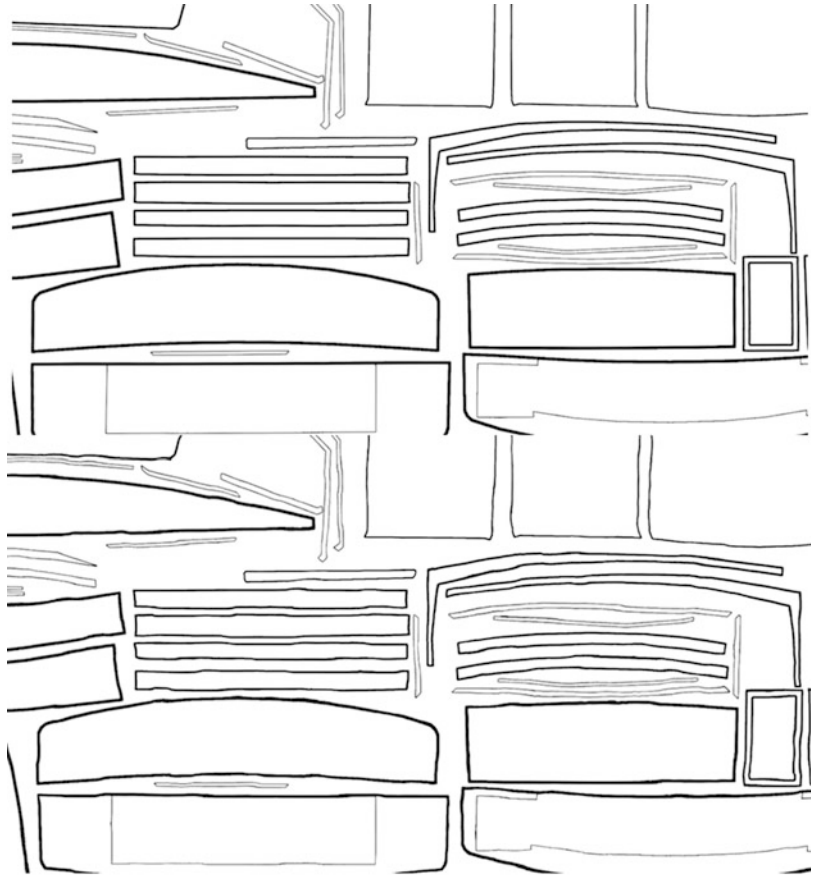
Comic Arts in Games, Asset Production, and Rendering, Fig. 3 Character with handmade line art texture

the ease of access to the source code if any change in the renderer is required to create the desired effects.

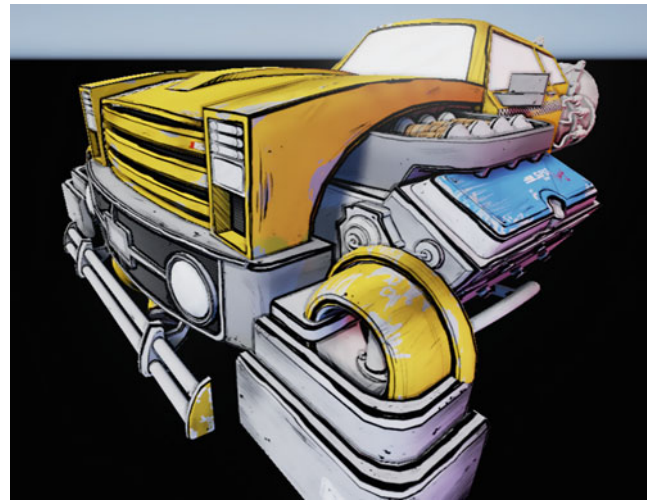
Hatching Shading Method and Line Art

Comic book art often uses different hatching techniques unique to its artist. Our goal was to minimize the texturing efforts in video game production pipeline. After trying different methods, the tonal art map pattern introduced in real-time hatching (Praun et al. 2001) seemed like the best option for creating seamless hatching patterns. Unfortunately, it didn't match the desired quality in the case of a repeated use especially on flat surfaces. We decided to limit the use of hatching shading on background organic objects.

The desired effect is achieved not by implementing a hatching shading in real time but

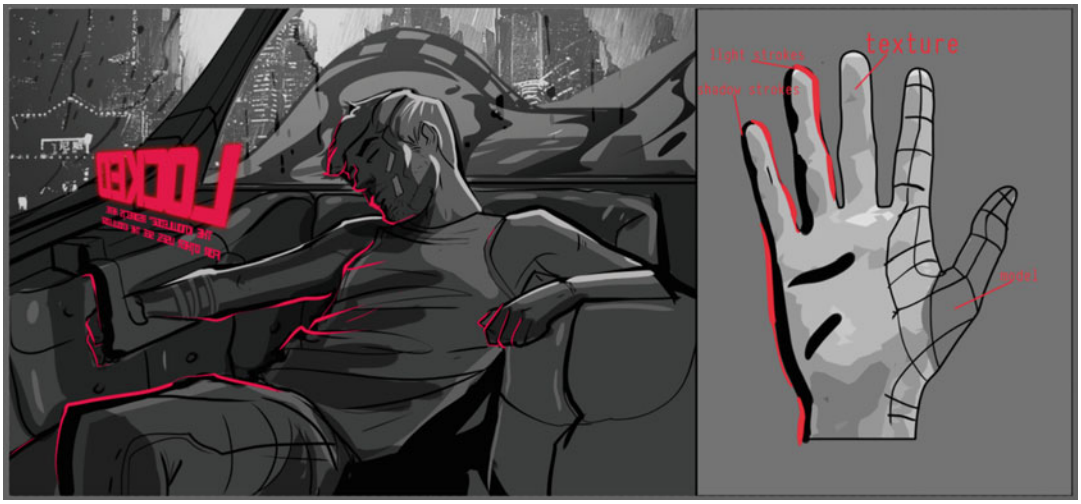


Comic Arts in Games, Asset Production, and Rendering, Fig. 4 Distortion on the UV outlines



Comic Arts in Games, Asset Production, and Rendering, Fig. 5 Final Image with distorded UV outlines

Comic Arts in Games, Asset Production, and Rendering, Fig. 6 Inlines with lighter line color



Comic Arts in Games, Asset Production, and Rendering, Fig. 7 Outline reflecting the color of a light source

Comic Arts in Games, Asset Production, and Rendering, Fig. 8 Screenshot from Nowhere Studios upcoming game Dan Black where line art texture, distortion on UV, smoothed toon shading, and outlines have been used

by using a handmade line art texture drawn especially on the parts suggested by the ambient occlusion map by an artist.

Furthermore, the stylization of inner lines on hard surface models is achieved by adding a distortion on the UV outlines. This is a very similar technique to the one used in WYSIWYG NPR: Drawing Strokes Directly on 3D Models (Kalnins et al. 2002). This can be done either real time because the additional cost to GPU is negligible or while baking the texture so it can be modified manually if necessary. As UV outlines can be detected using an edge detection, the distortion process doesn't require any effort from the artist.

Outlines

Outlines are an important part of comic art. An edge detection algorithm is used to draw outlines. Edge detection is a post process; therefore, all of the methods create artifacts on their own. It is not possible to perfectly distinguish the object in the front from the background every time unless an inverted hull method introduced by "Guilty Gear X'rd technical presentation" (Motomura 2015) is used. The inverted hull requires the geometry to be drawn a second time; therefore, it is more costly.

Our edge detection draws the line to the pixel outside of the object, thus creating a proper silhouette of the object. The distance of the object from the background and the distance between the object and the camera are reflected in thickness and color of the line drawn.

Also inlines are drawn with a lighter line color similar to the technique used in suggestive contours for conveying shape (DeCarlo et al. 2003).

Comic book artists also consider lighting and geometry of the object while drawing the outline. This is a further research area for NPR.

The outline color can also reflect the color of the light source enlightening the object or it can be used as a second outline layer.

Toon Shader

Most art directors use toon shader to create paperlike characteristic. In video games, it is mostly difficult to achieve a good looking toon shader because of polycount limits. Hard transition between toon shading levels often gives away the low-poly geometry of objects. One solution to the problem is editing the normals of the model, but it requires time and effort. Our solution was to use smooth transition between toon shading levels.

Conclusion and Possible Exploration Topics

There are many further research topics including a better hatching pattern and technique, possibly using a deep learning methodology to analyze different comic art styles; an outline method reflecting light intensity and geometry; and a solution for easily editing the normal maps for better looking toon shading.

Comic art is one of the many possible traditional art styles one might try to imitate in 3D. Painting methods such as water painting, oil on canvas and many more, and also all the art movements, these techniques have been used with provide a very rich soil for non-photorealistic rendering research.

Cross-References

▶ Rendering Equation

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Command System

▶ Decoupling Game Tool GUIs from Core Editing Operations

Commercial Rights

▶ Computer Games and the Evolution of Digital Rights

Comparative Studies

▶ Cross-cultural Game Studies

Competition

▶ StarCraft Bots and Competitions

Competitive Video Games

▶ Fortnite: A Brief History
▶ Professional Call of Duty Player Matthew "Nadeshot" Haag: An e-Sports Case Study
▶ Super Smash Bros. Ultimate and E-sports

Compressor/Decompressor

▶ Postproduction in Game Cinematics

Computational Steering for Computational Fluid Dynamics

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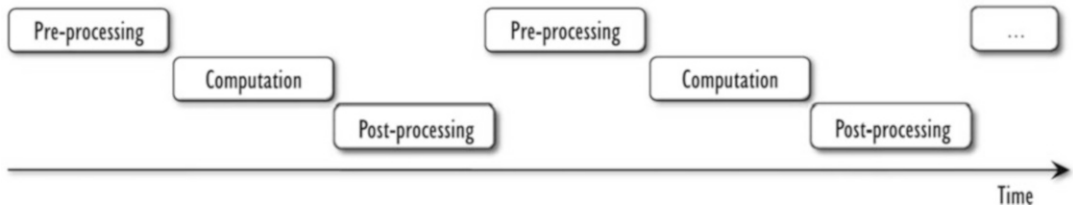
Definitions

Computational steering	is the practice of manually intervening with an otherwise autonomous computational process in order to change its outcome.
Computational fluid dynamics (CFD)	is the prediction of fluid flow by numerical methods.
In situ *visualization*	refers to the visualization of result data at runtime.

Introduction

Most computational fluid dynamics (CFD) simulations require massive computational power, which is usually provided by traditional high-performance computing (HPC) environments. Often, simulations are executed on a massive number of CPU cores (<check>O</check> (1000)) that are hosted in a remote supercomputing center or an in-house supercomputing facility. Due to several limitations of HPC environments, the majority of present CFD simulations are usually executed non-interactively, although interactivity of the simulation process is highly appreciated by scientists and engineers.

In this entry, different approaches for interactive CFD simulations are briefly reviewed. As



Computational Steering for Computational Fluid Dynamics, Fig. 1 Traditional CFD process chain (Linxweiler et al. 2011)

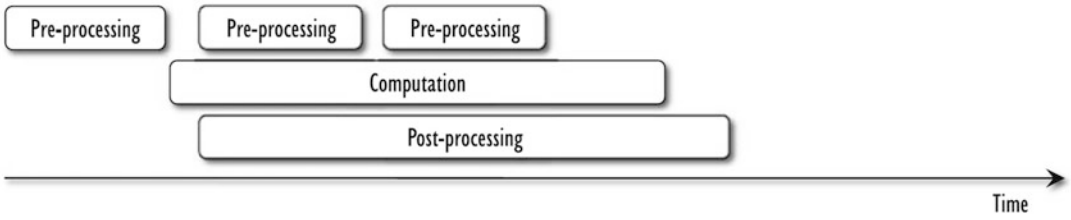
opposed to remote rendering solutions, where data to render is pulled over a connection to remote rendering stations, a recent trend is to harness the parallel computational power of locally available many-core CPUs, graphics processing units (GPUs), or mobile devices for general-purpose applications. Starting from the state of the art in conventional CFD simulations, this entry focuses on hardware resources that are available *on the desktop* and *in the palm of your hand* as a basis for computational steering.

State of the Art in CFD Analysis

Traditionally, CFD analyses are done in a cyclic sequence of independent steps (Fig. 1). The simulation is usually set up in a preprocessing phase by defining the geometry of the flow domain as well as the initial and boundary conditions. After that, the calculation is carried out for a fixed number of time steps. As CFD simulations are computationally intensive, they are usually executed on high-performance systems. In such high-performance computing environments, the job is typically submitted to a queuing system and is not executed until the needed resources become available. The simulation may run for hours, days, or even longer until in the end the results are stored on a file system. To conduct post-processing, this data is often transferred to the users' workstation to evaluate the simulation and identify errors or possible modifications to model parameters that will be applied in a subsequent iteration. The whole process chain is illustrated in Fig. 1.

For each adaptation that is to be made to the computation, the whole process has to be repeated. User interaction is obviously rather limited and takes place exclusively during the preprocessing/modeling phase. Not surprisingly, it is a long-term wish of scientists and engineers to closely interact with their simulations while they are running. Since the influential report of the US National Science Foundation (NSF) in 1987 (McCormick et al. 1987), new forms of scientific visualization have evolved that are quite different from traditional post-processing. The approach commonly referred to as *computational steering* has been the subject of widespread interest in the scientific CFD community. The name goes back to one of the first applications of interactivity demonstrated by Marshall et al. (1990) who presented an interactive simulation of a turbulence model using a simulation of Lake Erie. In the following years, major contributions to the development of the computational steering paradigm by Liere, Mulder, and van Wijk (Van Liere and Van Wijk 1996; van Liere and Mulder 1997; van Liere et al. 1997; Mulder et al. 1999; Mulder and van Wijk 1995; Van Wijk et al. 1997; Van Wijk and Van Liere 1997) as well as Johnson and Parker (Johnson et al. 1999; Johnson and Parker 1994; Parker et al. 1997a; Parker and Johnson 1995; Parker et al. 1997b, c) are recognized.

A first step to more interaction with the simulation is the so-called *tracking* (Marshall et al. 1990) approach, which is sometimes also called *monitoring* (Hart and Kraemer 1999). After each time step, intermediate results are sent to the visualization pipeline for analysis. This enables the scientist to analyze the results in an early stage of the simulation to stop and restart the simulation when required. The next step is



Computational Steering for Computational Fluid Dynamics, Fig. 2 Pipeline of computational steering (Linxweiler et al. 2011)

computational steering which goes a lot further. According to van Liere et al. (1997), it can be considered as the ultimate goal of interactive computing. Mulder and others define computational steering as interactive control over a computational process during execution (Mulder et al. 1999). As such, computational steering closes the loop in that scientists and engineers can respond to the results immediately by interactively changing the setup of the simulation without the need to restart the whole process. As changes to parameters become more instantaneous, the cause-effect relationship becomes more obvious so that scientists can develop an intuition regarding the effect of a parameter, detect bugs, or deepen their understanding of the physics or the algorithms of the considered problem (Parker and Johnson 1995). With computational steering, "What if?" questions can be answered more efficiently and therefore guide the investigation at runtime (Geist II et al. 1996). This leads to a significant increase in productivity and a vast reduction of the time between the generation of the results and exploration. Accordingly, the timeline of the computational steering pipeline can be summarized as depicted in Fig. 2. In addition to efficiency, computational steering also stimulates communication and discussion within engineering teams by providing immediate visual representation of the model and results (Van Wijk et al. 1997). These benefits make computational steering an important tool, especially for rapid prototyping and debugging, but also add value in other areas, e.g., for teaching (Linxweiler et al. 2007; Glessmer and Janßen 2017).

Conventional CPU-Based Approaches

Although the advantages of computational steering are obvious, its application in CFD, as well as other sciences, is still rare (Pickles et al. 2005; Wenisch et al. 2005; Wright et al. 2010; Janßen and Bindick 2019). There are various reasons for this, more often related to integration with traditional HPC systems. First and foremost, the development of a computational steering system is a complex task, as it requires the integration of multiple disciplines such as physics, numerical methods, user interface design, 3D graphics, and HPC (Parker et al. 1997c; Van Wijk et al. 1997; Linxweiler et al. 2011). Furthermore, HPC environments are traditionally not set up for interactive usage. Instead, the resources are remote to the user and typically managed by a queuing system. Computational steering violates many of the assumptions on which resource management systems rely. Therefore most site managers believe that interactivity wastes CPU cycles (Johnson et al. 1999). As a consequence most research, as well as commercial CFD codes, do not support interaction. The exceptions are, e.g., Kühner (2003), who demonstrated a 3D virtual wind tunnel, which combines an HPC system running the CFD simulation with a virtual reality system for facilitating exploration and handling user interaction. The application allows for dynamic adjustment of scalar parameters as well as manipulation of primitive geometries during execution. Based on this work, Wenisch (2008) presented a simulation of a ventilation system for operating theaters which also works with complex geometries. In cooperation with Borrmann (Borrmann 2007; Borrmann et al. 2006), this application was

extended to allow for collaborative exploration of the simulation results by multiple distributed users.

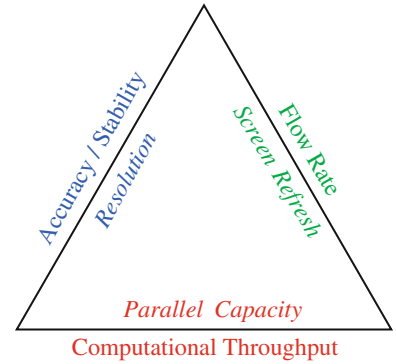
How to Measure Interactivity

For interactive simulations, it is essential that developers maintain awareness of the interplay between the perceived rate of flow to a user, the accuracy/stability of a calculation, and the computational throughput. These are the key qualities of an interactive simulation as discussed in Harwood and Revell (2018) and Harwood (2018, 2019) and are controlled therein through configurable parameters. The accuracy and stability of the numerical solver are controlled by the simulation resolution, the perceived flow rate to the user through the refresh frequency of the visualization, and the computational throughput through the amount of parallel compute capacity used (c.f. Fig. 3).

As the accuracy increases, so does the resolution of the calculation. This puts increasing demands on computing resources, typically shrinking the time step size. Thus, more iterations need to be completed for the same amount of time to be simulated. At a fixed computational throughput, the simulation thus evolves slower, and the refresh rate may need adjusting to compensate.

The real-time ratio T_r (Harwood and Revell 2018) expresses the ratio of the time simulated to the time taken to simulate that time interval with $T_r = 1$ being the precise definition of a real-time simulation. This provides an improved measure of the capability of an interactive calculation compared to just examining throughput alone. However, even if a calculation is running at a real-time rate, the refresh rate controls how the flow is perceived by the user. Therefore, for interactivity, we need to consider all these parameters simultaneously as we discuss below.

Consider the following illustration: a simulation uses a $dt_{sim} = 0.01$ seconds. The throughput of the calculation is 50,000 grid cells every second based on our chosen compute device. The resolution of the calculation is such that we have a 2D domain 60×30 cells. This gives 1800 grid cells in the domain. Our compute device can then update the whole grid around 28 times each second. Each time step on our given compute device takes $dt_{wall} = 0.036$. Thus we have a $T_r = 0.01/0.036 = 0.28$. Therefore the simulation is running at 3.6x slower than real time. Increasing the resolution may increase the throughput (assuming resources have not been saturated). So doubling the resolution, if the device scales perfectly, would double the throughput to 100,000 cells every second. However, for some numerical methods, such as the lattice-Boltzmann method, to control errors and maintain stability, the time step would then need to be divided by four (Krüger et al. 2009). Thus, $dt_{wall} = 0.036$ still but $dt_{sim} = 0.0025$ and hence $T_r = 0.0025/0.036 = 0.07$. Hence, the ability to achieve true real-time performance is dependent on both suitable numerical methods and suitable hardware and cannot be achieved by one alone.



Computational Steering for Computational Fluid Dynamics, Fig. 3 The interplay between the perceived rate of flow to a user, the accuracy and stability of a calculation and the throughput of the solver are important for interactive applications

Real-time ratio just considers the performance at a computational level. A user of an interactive simulation is probably less interested in whether the simulation is strictly real time but more interested in whether they see a smooth, yet accurate and expressive, visualization of the data in situ. This forces us to consider other factors when defining performance. For simulations to be visualized smoothly in situ, it is widely accepted that we need a refresh rate of our display of at least 24 frames per second (FPS). Returning to the previous example, we would need to update our display every iteration, giving us a frame rate of

$28 > 24$ FPS. Based on the throughput, we have a maximum perceived flow scale of $u_p = 28$ cells per second – i.e., the rate at which information is passed through our grid, one cell at a time. If we have 60 cells across a 30 cm width screen, then this is a perceived physical flow rate of 0.14 m/s. Of course, this is an upper limit achieved by acoustics in most cases, and typically, flow features of interest will propagate much slower than this. We must be aware that structures of interest may then propagate too slowly for interactive applications. In these situations, our options are:

- Reduce refresh rate – encourage information to propagate more before updating the screen.
- Reduce the time step (resolution) – often difficult without introducing errors and instabilities in the numerical method.
- Increase the parallel capacity (throughput) – often limited by available computing resources.

As is discussed in Harwood (2019), as well as in our example above, the adjustment of any one of these parameters in the pursuit of more speed, a higher accuracy, or a smoother frame rate may have an adverse effect on another metric; thus, the pursuit of interactive simulations is almost always a delicate balancing act.

Using Mobile Devices for CFD

Mobile devices (phones and tablet computers) are perhaps uniquely placed for computational steering activities as user interaction with a mobile form factor is more convenient and intuitive. However, the use of mobile hardware for conducting CFD simulations of a degree of fidelity appropriate for engineering applications has been largely unexplored in the literature to date. Being able to perform *interactive* CFD simulations on mobile devices allows the development of portable, affordable simulation tools that can have a significant impact in engineering design as well as teaching and learning. The work of Harwood and Revell (Harwood and Revell (2017, 2018); Harwood 2019) explores the feasibility of developing performant fluid dynamics applications for mobile CPUs and GPUs. They develop interactive CFD simulations suitable for mobile devices and test their implementations for a range of problem sizes. In Harwood and Revell (2018), the authors implement their simulation software using the CUDA API and use a combination of software development kits to compile the application. The application successfully harnesses the mass parallelism and power efficiency of the GPU to be over 300x more efficient in terms of combined throughput and power consumption than the earlier CPU implementation (see Table 1). However, the work outlines the complexity at present in creating mobile applications which can efficiently leverage the raw power of mobile hardware.

Recent work (Harwood (2019)) has explored the use of multiple mobile devices running a distributed interactive simulation implemented using OpenGL ES compute shaders and Java sockets. Contained within an Android application, the work examines the role of communication strategy as well as refresh rate (termed render frequency f_R in the entry) on the performance of the simulation as discussed in section. The render frequency proved to be an influential factor in terms of overall computational throughput (Table) with the time to render the screen not insignificant when performed frequently. Furthermore, the restriction of OpenGL render threads to 60 FPS by the Android OS artificially limited the throughput. This is something that is universally applicable for general-purpose GPU computing

Computational Steering for Computational Fluid Dynamics, Table 1 Comparison between CPU and GPU implementations. (Data taken from Harwood and Revell 2018)

Measure	CPU (6-tasks)	GPU (3 warps block)
MLUPS	1.1	14.83
Memory usage (MB)	5.9	6.0
Energy/physical second ($kW\,h \times 10^{-3}$)	5.23	0.232
Real-time ratio (T_r)	0.0395	0.832

which makes use of OpenGL for its implementation (Fig. 4).

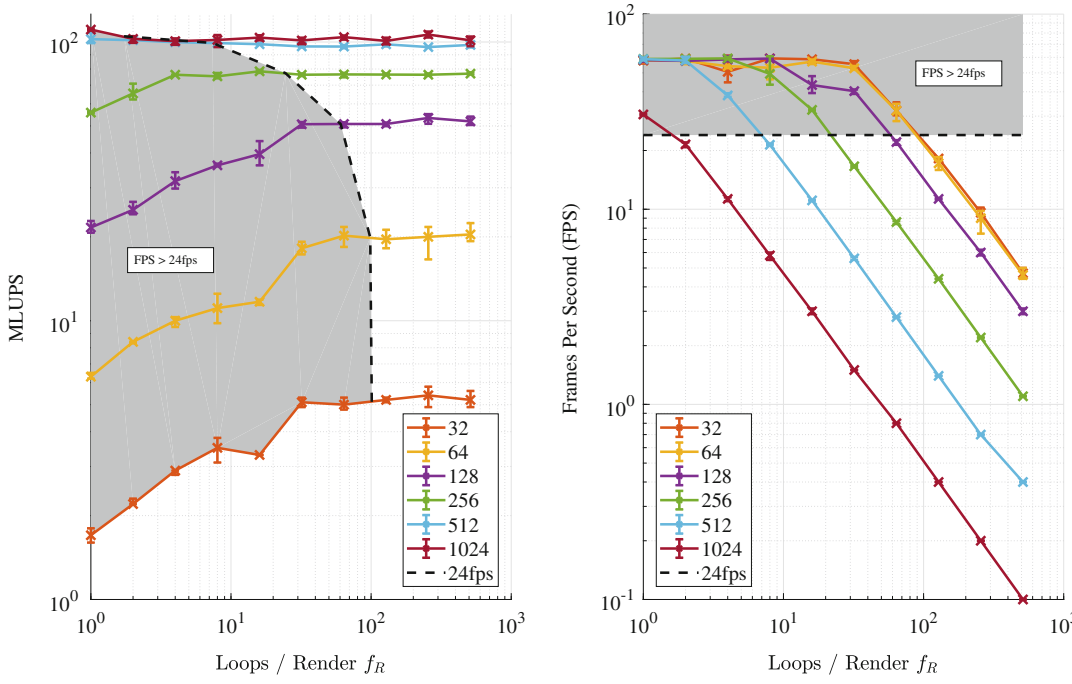
The time taken to conduct the 2D simulations over a wide range of resolutions, as expected, was significantly lower than the time taken to pass information between the networked devices. As such, the results of testing multiple devices (Fig. 5) illustrate two key findings: first, that with calculations at very high resolutions, it is difficult to hide this communication latency by adjusting the render frequency and perceptible stuttering in the visualization is inevitable. Second, the weak scaling of the algorithm across multiple devices is relatively efficient; thus, large-scale simulations across a cluster of mobile devices is likely to be possible.

Types of Mobile Application Development

Developing applications for mobile devices is a similar process to developing a desktop application with a user interface. However, the languages involved and tool chains used to build the software can vary dramatically from platform to platform and, thus, have a huge effect on the performance of the final application. Applications can be developed as native applications, web applications, and hybrid applications.

Native applications use the native languages and toolkits associated with a platform. On Android, codes written in Java and C++ using the Android SDK/NDK are forms of native development. On iOS, code is written in Swift or Objective-C. Native applications are fast and can leverage the full set of device capabilities through platform-specific APIs. They give the best user experience but at the expense of having to develop a different code base for every target platform.

Cross-platform applications can be developed using a higher-level suite of tools and then built for multiple platforms from the single, common code base. Web applications are the simplest approach to cross-platform development. Apps



(a) Performance in terms of MLUPS.

(b) Performance in terms of FPS.

Computational Steering for Computational Fluid Dynamics, Fig. 4 Performance of the current GLSL-based application for a combination of different resolutions n and render frequencies f_R. The target region for interactive simulations is 24 FPS and is indicated by the shaded regions. (Taken from Harwood 2019)

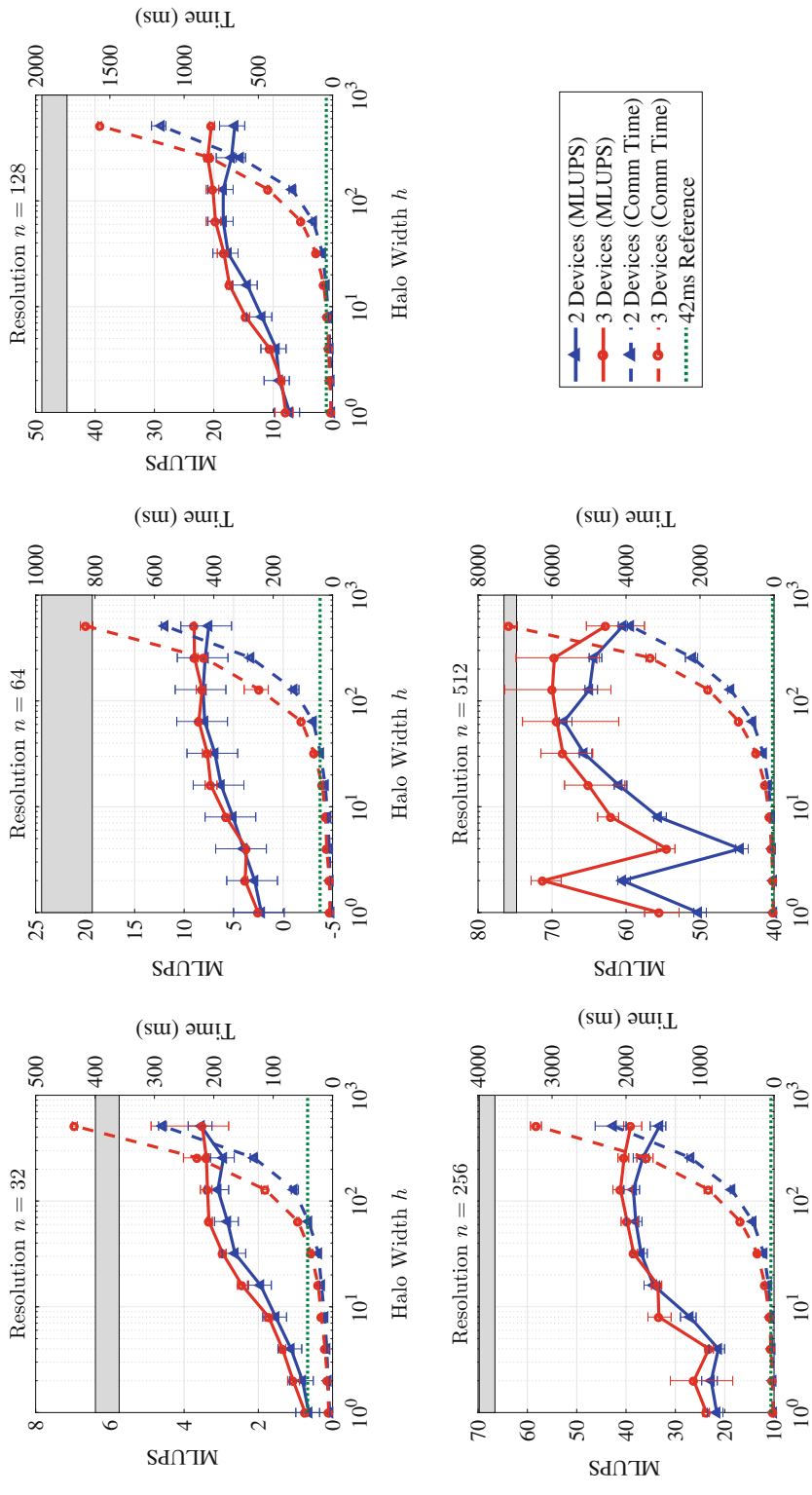


Fig. 5 Performance in million lattice updates per second (MLUPS) (left axis) and time taken to conduct communication (right axis) of the multi-device application. Shaded gray rectangles indicate the range of performance in MLUPS of the serial application run with the same configuration of resolution n and render frequency f_R. The green dotted line represents a time of 42 ms, the time of a single frame at 24 FPS. (Taken from Harwood 2019)

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are quicker to develop and easier to maintain but lack access to all device capabilities and are restricted in many respects by the web browser within which they run. Typically these applications are written using a platform agnostic API like the JavaScript, CSS, HTML, or combination of Cordova (PhoneGap).

Hybrid applications are usually a combination of the two approaches with some code written in a platform agnostic language leveraging a cross-platform API for most device functionality. UI elements are translated to native UI components, but some functionality may still need to be implemented on a per-platform basis.

For maximum performance, such as would be required by simulation applications, native approaches are recommended. The just-in-the compilation of the Java Virtual Machine on Android can further be circumvented by writing performance-critical parts of code in C++, precompiling these components as libraries using the Android NDK, and then linking these components to the Java application through the Java Native Interface (JNI). This approach is taken in Harwood and Revell (2018) to maximize performance while enabling the use of CUDA for a supported mobile GPU.

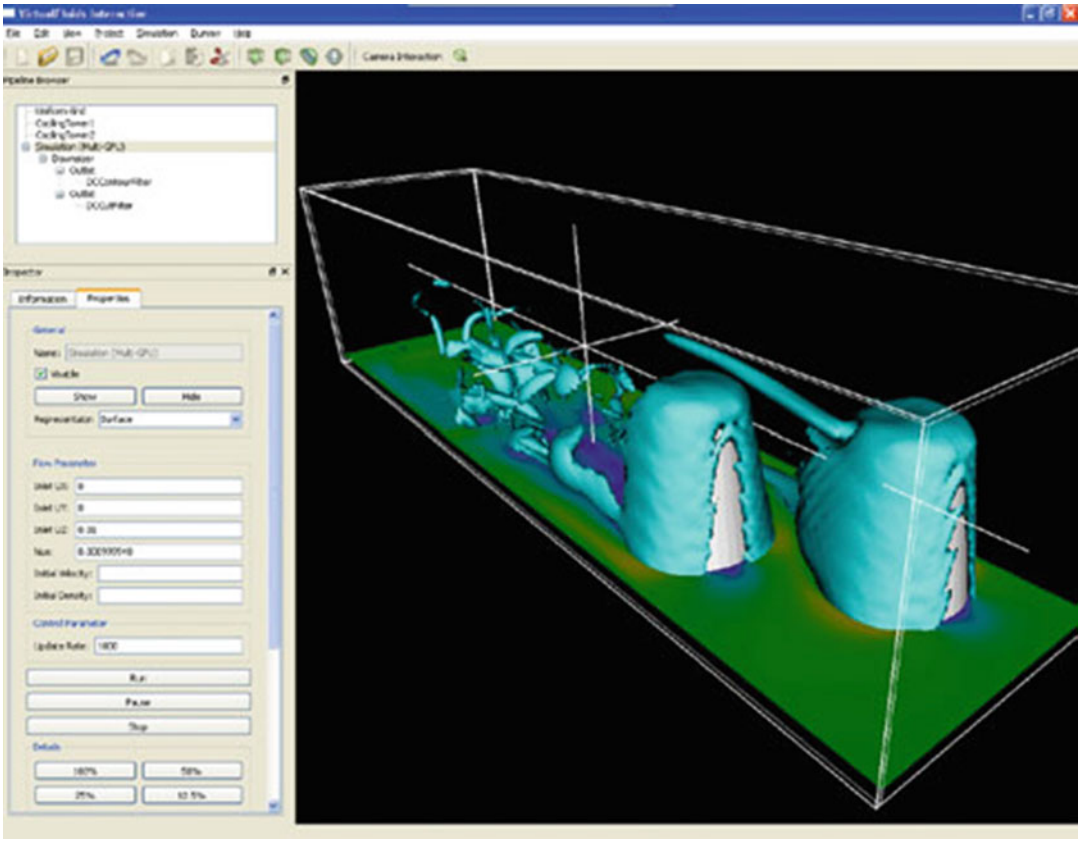
Challenges of Using Mobile Devices for High-Performance CFD

Mobile device hardware is designed to maintain a delicate balance between performance and power efficiency. In addition, mobile device software is designed to enable an uninterrupted user experience ensuring (UIs) remain available at all times. All applications written for mobile devices must necessarily be multi-threaded. The restriction on the number of parallel threads and the reduction in priority of threads other than the UI thread are compromises applied by the mobile operating system (OS) in order to maintain this balance.

Developer design guidelines, such as those provided by Google for Android application design, are an essential source of advice when writing native applications where delivering every last bit of performance possible is the primary aim. However, when developing for mobile devices, we must accept that the compute capacity is simply not on the same level as desktop systems. Researchers have recently explored the potential of using local clusters of mobile devices to share computing power through peer-to-peer networking (Harwood (2019)). Ultimately, Harwood and Revell (2018) conclude that the trade-off between accuracy, speed, and power consumption is explored with the choice of problem resolution ultimately being characterized by a desired accuracy, flow speed, and endurance of a given simulation.

GPU-Based Approaches

In addition to mobile devices that allow to run numerical simulations in the palm of your hand, another recent trend is to harness the parallel computational power of graphics processing units (GPUs) not only for rendering purposes but also for general-purpose applications. Effectively, the availability of these compact, highly efficient accelerator boards introduced a new era of local supercomputing. NVIDIA introduced the first GPU in 1999 (NVIDIA 2013a) as a dedicated rendering machine, handling all pipeline steps from vertex generation to pixel operations. Prior to the release of the GeForce 256, the vertices of objects were generated and processed on the central processing unit (CPU) and then sent to an add-in graphics accelerator like the 3dfx Voodoo card, which generated and processed primitives and fragments, and finally operated on the pixels (Kirk and Hwu 2010; Patterson and Hennessy 2011; Akenine-Moller et al. 2008). In late 2006 NVIDIA then released the GeForce 8800 (G80), one of the first unified graphics and computing GPUs (NVIDIA 2013a). Using the NVIDIA CUDA API and the built-in CUDA cores of the GeForce graphics card, programmers without any background in graphics or familiarity with the graphics pipeline were now able to implement their code on GPUs. This level of graphics card utilization for general-purpose applications is called GPGPU computing. Ever since the release of NVIDIA's G80, a continuous growth in compute capability regarding floating-point operations per second (FLOPS), memory bandwidth,

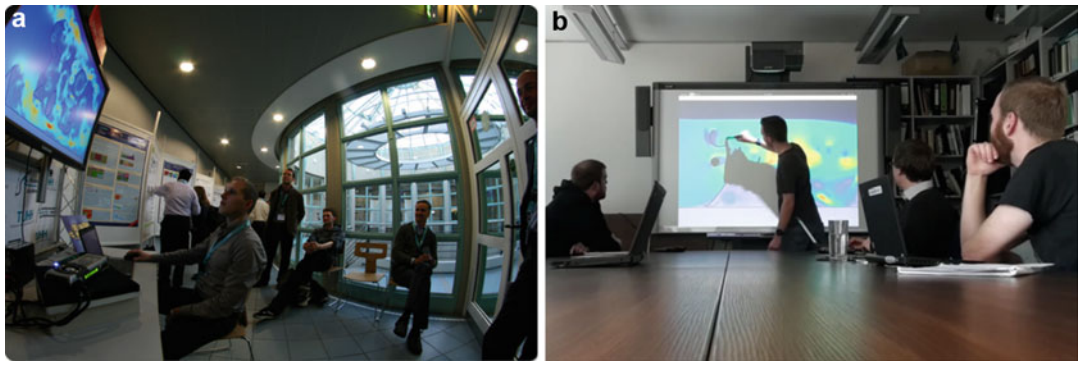


Computational Steering for Computational Fluid Dynamics, Fig. 6 The VirtualFluids Interactive simulation environment showing the airflow around cooling towers. (Taken from Linxweiler et al. 2011)

and number of transistors and streaming processors took place (NVIDIA 2013b). As an alternative to traditional massively parallel computing, GPU computing has also gained popularity in the CFD community as it allows for interactive 3D simulations at reasonable problem sizes, as discussed in the following.

Hybrid Visualization Approaches (GPU + CPU)

Linxweiler et al. (2007, 2011) adapted GPU computing for computational steering in CFD and demonstrated the benefits from the use of GPUs. They developed a single desktop application (VirtualFluids Interactive) (Fig. 6) integrating a complete pipeline for interactive CFD simulation including pre- and post-processing as well as the simulation. In this approach the preprocessing and visualization are running on the CPU; likewise, the simulation is executed on the GPU. The example shows that convergence of massive parallel computational power and a steering environment into a single system significantly improves the usability, the application quality, and the user-friendliness. Furthermore, using multiple GPUs, the approach allows for 3D simulations close to real time even for reasonable problem sizes. In this case, responsiveness significantly benefits from avoiding common bandwidth and latency bottlenecks inherent with traditional HPC clusters. Those can be avoided as GPU computing does not generally require network communication, which also reduces the complexity of the application. Compared to traditional massive parallel environments, GPUs are affordable for small to medium enterprises and do not require additional HPC knowledge from the end users. In addition, GPUs reduce power consumption with a much better performance-per-watt ratio.



Computational Steering for Computational Fluid Dynamics, Fig. 7 ELBE*vis* in action: (**a**) during the poster session at the GACM 2013 conference in Hamburg, Germany, (**b**) in a typical classroom situation on a smart board. (Taken from Koliha et al. 2015)

Direct CUDA-OpenGL Interoperability

While the previous approach benefits from a featured user interface with maximum usability, the method still relies on frequent data transfer from the GPU device back to the host and vice versa. Such extensive communication via the PCIe bus hinders real-time simulations and interactivity, as already discussed. For some applications, alternative concepts where visualization and data management happen completely on the device have shown to be more feasible, without moving or copying any data from or to the host during the simulation at all.

Delbosc et al. (2014) present an implementation of an optimized three-dimensional real-time thermal and turbulent fluid flow solver with a performance of half a billion lattice node updates per second. The method then has been applied to study the time evolution of the turbulent airflow and temperature inside a test chamber and in a simple model of a four-bed hospital room (Khan et al. 2015).

The authors of Koliha et al. (2015) present ELBE*vis*, a framework that is based on OpenGL-CUDA interoperability (NVIDIA 2013b) and maps OpenGL buffer objects, to the CUDA context for use in its respective memory space. This allows CUDA routines to read and write from and to data arrays that are then used for rendering. The OpenGL graphics API has been chosen by the authors to generate the images displayed on the screen due to its widespread use and platform independence. OpenGL wraps graphics driver calls into C commands and provides additional functionality for vertex, primitive, and fragment generation and processing. Libraries such as the OpenGL extension wrangler (GLEW) or the OpenGL utility library (GLU) were utilized to make use of OpenGL function bundles.

Due to the minimal-invasive concept and the high performance of the numerical solver, ELBE*vis* allows for very responsive interactions between the user and the numerical simulation. In Fig. 7, two examples for the use of ELBE*vis* are shown, for a 2D application case with simple inlet/outlet boundary conditions on the left/right end of the computational domain. The simulation is run on an NVIDIA GTX Titan board that is attached to an off-the-shelf laptop through an ExpressCard slot. The user can control the visualization by selecting the desired visualizer features, color maps, and so on. On top, the computational domain can be modified by freely drawing shapes. The effects on the flow field can immediately be observed, which makes the coupled solver a great tool for understanding the basics of fluid mechanics. Glessmer and Janßen (2017) discuss how to successfully use ELBE and ELBE*vis* in different teaching scenarios for Bachelor, Master, and PhD level work.

Apart from these interactive real-time applications, ELBE*vis* can also be used for simulations that run *near* real time, as the visualizer still

allows to control of the simulation progress and to analyze the flow field characteristics. For example, Überrück and Janßen (2017) elaborately discuss the simulation of wave impact. The highly resolved numerical simulations were run approximately one order of magnitude slower than real time and could benefit from the innovative visualizer concept. Thanks to the interactive monitoring of the simulations, without time-consuming file-I/O and subsequent visualization with CPU-based visualizer tools, information on the sloshing process and the model quality could be extracted easily as discussed in the entry.

Summary

Tremendous developments in recent years have brought more and more computing power to the desktop and into the end user's palm. Harnessing this power requires innovative concepts for the visualization of the numerical data and, at the same time, allows for innovative new concepts of computational steering. Successful examples include interactive steering in the context of conventional CPU solvers, solvers that make use of GPU acceleration and, most recently, first attempts to use the compute power of mobile devices for numerical simulations and computational steering.

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Computed Fluid Flow

▶ Fluid Simulation

Computer Aided Design

▶ Collaborative Engineering and Virtual Prototyping Within Virtual Reality

Computer Aided Engineering

▶ Collaborative Engineering and Virtual Prototyping Within Virtual Reality

Computer Baduk

► Computer Go

Computer Games and Artificial Intelligence

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Synonyms

Computer Games: Video Games
Artificial Intelligence: Machine Intelligence; Artificial Cognitive Intelligence

Definition

Computer Games are games that are realized in one form or another using digital hardware. Artificial Intelligence is commonly considered a branch of Computing Science which has matured to become a field of its own right. It is concerned with the creation/simulation of intelligent behaviour in/by machines.

Background

In the context of computer games and the computer games industry, games have become an essential part of the software and entertainment industry (Saarikoski and Suominen 2009). Recently there is increased interest in games (Lowood 2009) from a sociological, cultural, and educational point of view (Hildmann and Hildmann 2012a, b). For decades now, it has been argued that games and the playing of games are culturally significant (Mechling 1987).

Games and Game Theory

Games have traditionally existed in versions involving more than one player (Books 2010) and those that do constitute a formalized form of interaction that is more than physical activity or information exchange. The literature on games in general – as well as on specific games and their individual rules – is extensive (Tylor 1879). In the field of game theory, which is concerned with the formal analysis of games and their properties, one traditionally (Nash 2001; Osborne and Rubenstein 1994; von Neumann and Morgenstern 1974) distinguishes a variety of game types:

- *Noncooperative vs. cooperative games*: With regard to the actions available to a player during a game, we call an action *primitive* if it cannot be decomposed further into a series of other, smaller actions. The distinction is then made on the basis of whether such primitive actions are performed by individual players (*noncooperative*) or by groups of players (*cooperative*).
- *Strategic vs. extensive games*: A game is strategic if all decisions of all players are made a priori (i.e., before the start of the game) and independent of the opponent's decision (e.g., *Paper-Rock-Scissors*). Extensive games allow for decisions to be made during game play and with respect to the opponents moves (e.g., *Chess*).
- *Perfect information vs. imperfect information*: In, e.g., *Chess* both players have perfect insight into the state of the game; thus *Chess* is a game of perfect information. However, in most card games, there is an element of uncertainty as one normally does not know the distribution of cards for the opponents. The latter games are imperfect information games.

Today, games are mainly of interest to the AI community if they are too complex to calculate all possible variations. For example, the game *Nim*, though having a rich mathematical theory behind it, is small enough to calculate a winning strategy (Conway 2001). Due to its mathematical

foundation, it has left its mark on combinatorial game theory through terminology (e.g., *nim-addition* and *nimsum*) (Jørgensen 2009). However, it is possible to precalculate the moves and play a perfect game as there are known algorithms for doing so (Spencer 1975); thus the theoretical winner is already known, and there exist straightforward algorithms to determine which side will have this advantage (Bouton 1902). Due to this, the game is uninteresting today for both game theoreticians and researchers in AI. This was not always the case though, and in the early years, a number of devices were built to play the game: e.g., "Nimatron," built by Westinghouse for the New York Worlds Fair in 1940 (http://www.goodeveca.net/nimrod/nimatron.html) or "Nimrod," developed for the Festival of Britain in London in 1951. These games were the highlights where they were shown, with Nimatron playing 100.000 games (and winning 90.000) and Nimrod "taking on all comers" at the Festival in London (Jørgensen 2009).

Games and Artificial Intelligence

Yan (2003) lists artificial intelligence as an inherent design issue for online games, and indeed, "appropriately challenging" AI is considered to be crucial to the commercial success of a game (Aiollil and Palazzi 2009). Generally it can be said that "non-repetitive, adaptive, interesting, and in summary intelligent behavior offers a competitive edge for commercial games" (Naddaf 2010).

As the combinatorial challenge of complex games such as *Chess* and *Go* (discussed below) is successively mastered, some emphasis (e.g., Hildmann and Crowe 2011) is placed on designing AI players that instead of playing *very well* can play *realistically* in the context of playing non-repetitively and in an interesting way. Emphasis is placed on intelligent *behavior* (Hildmann 2013) in the way that a human player would play, including the handicaps, shortcomings and common mistakes made by humans (Hildmann 2011).

Besides the commercial interest of the gaming industry, the research field itself has always had a large interest in games. The prime example is the game of Chess – famously called the "Drosophila of AI" (McCarthy 1990). It was used by key figures in the field of artificial intelligence (such as, e.g., Claude Shannon 1950; Allen Newell et al. 1988; Herbert Simon 1970) in the context of their research on machine and human intelligence. The interest in this game predates the computer age: Charles Babbage already considered using his "Analytical engine" to play Chess in the 1840s, and by 1949 researchers on both sides of the Atlantic were advancing theoretical approaches to automate the playing of this game (Hsu et al. 1995). Similarly, *Checkers* was used by, e.g., Arthur Samuel to study learning (Jørgensen 2009).

In the past, specifically the Atari 2600 game console has been used extensively as a platform for developing and demonstrating AI algorithms. The reasons for this are the that there are over 900 game titles available for the Atari 2600 console, the games are simple and concentrate on the problematic aspects of the game (while newer games showcase the latest in video and graphic performances), they have a small and discrete action space, and many emulators are available (Naddaf 2010). Games will continue to be a focal point of AI research. For example, the game *Octi* (Schaeffer and van den Herik 2002) is a game specifically invented to be resistant to computer algorithms.

Ethical Considerations

Many things, including far-reaching business and political decisions, can be modeled as a game, and the application of artificial intelligence to the therefore broad area of games has stirred many controversies over the years. Among the relevant discussion topics are whether a computer can be said to *play* at all and whether computers should be *allowed* to play with (meddle in) some of the more serious matters that can be cast into a game-theoretic model.

For example, Weizenbaum (1972) and Wiener (1960) wrote on the moral and ethical issues of AI and allowing computers to make decisions, the latter being criticized by Samuel (1960) and the

former by Coles (1972). Taube (1960) wrote in response to Wiener (1960) that machines cannot *play* at all. He supposes that the act of *playing* is in line with *enjoyment*, and the author makes the distinction between the notions of *game* as it is "used in the usual sense" contrasted with *game* after it is "redefined by computer enthusiasts with nothing more serious to do."

Johnson and Kobler (1962) agree with Wiener (1960) that machines can be original but warn of allowing them to play war-games and simulations of nuclear war, as their predictions might not be entirely accurate and they would lack the understanding of all the values that need to be considered (i.e., to gain the insight ultimately exhibited by the fictional computer system "Joshua"). While the moral issues of artificial intelligence and political decisions have recently become a mainstream matter of discussion, this was already discussed in the context of game theory and its application to the nuclear "first strike" doctrine in the cold war. It was a well-known matter of disagreement between Wiener and vonNeumann; the latter advocated the idea of a preemptive nuclear strike on Russia. His argument was that their reasoning would lead them to the same conclusion, making it simply a matter of time before one side struck first. Since the mid-1990s, computers have successively dismantled the reign of human players in the realms of perfect information games. More recently, this has also happened in games with imperfect information, where intuition or the understanding of complex real-world relationships is required. Machines are increasingly mastering the decision-making in situations that go beyond those found in Chess and Go. Whether mastery of these situations includes the understanding that, e.g., "mutually ensured annihilation" is undesirable even if it constituted a victory *by points* is a question worth asking (but not the subject of this entry).

Landmark Artificial Intelligence Victories

Games are culturally important (Sutton-Smith 1986) and have been used for millennia to allow humans to exercise the brain (Smith 1956) and to compete against each other on the basis of mastery of skill and *intelligence*.

Therefore, games have been of large interest to the AI community, and the design of programs that can match the performance of human top players has been considered the ultimate achievement for a long time. Once a program can hold its own against a human, the next step is to try and outperform humans, and since the mid-1990s, one game after the other has been mastered by computers: in 1995 a program called "Chinook" played the game of Checkers at world class level and succeeded in beating one of the world's best players (Kroeker 2011). In 1996 "Deep Blue" beat the reigning world champion in the game of Chess for the first time in history (Kasparov 1996), and 1 year later, it won an entire chess tournament, ending the supremacy of humans in this game (Schaeffer and van den Herik 2002). The TV show game *Jeopardy!* was conquered decisively by "Watson" in 2011. *Poker*, a game of bluffing and intuition, was mastered in 2015 (Bowling et al. 2015) and within months from each other (December 2016 and January 2017), two programs, "Libratus" (Riley 2017) and "DeepStack" (Moravčík et al. 2017), significantly outperformed dozens of professional and top human players. Finally, the best human players of Go – the board game considered by many to be the last great stronghold of human superiority in games – recently succumbed to "AlphaGo."

Since 2005 the Stanford Logic Group of Stanford University, California is running the *General Game Playing Competition* (http://games.stanford.edu/) (GGPC) (Genesereth and Love 2005) which is inviting programs to compete in playing games. The games to be played are, however, unknown in advance, and the programs have to be able to compete in a number of different types of games, expressed in a Game Description Language (Love et al. 2008). "AlphaGo Zero" recently not only learned the games *Shogi*, *Chess*, and *Go* – all of which had defined computer programs for decades – from scratch (at a significant computational cost, Silver et al. (2017)), it also proceeded to beat the best programs currently available for each of these

games. This might be an indication that the GGPC competition might also soon come to an end. Progress is occurring at a nonlinear speed, and certainly in the area of artificial intelligence, the recent years have seen milestone events happen with increasing frequency.

Before we briefly elaborate on some of the most prominent examples of artificial intelligence systems winning against top human players, it should be pointed out that there does not seem to be a *silver bullet*, as the discussed games were conquered with different techniques and approaches. The game of Chess was essentially conquered by throwing sufficiently large amounts of computational resources at it (as well as training the program to play a specific human opponent) while the original program that mastered Go used advanced machine learning techniques (combined with *Monte Carlos Tree Search* (MCTS)) and had access to a large database of previously played games. Its revised version (which learned to play Go as well as Chess from scratch) relied on learning from massive numbers of games it would play against itself. In contrast, the program that won *Jeopardy!* applied probabilistic methods before selecting the most likely answer. A full technical discussion of these programs is beyond the scope of this entry; the interested reader is referred to the provided references for in-depth discussion on the matter.

Chess: Deep Blue

In his recent book (Kasparov and Greengard 2017), Gary Kasparov writes that over his career, starting at the age of 12, he played about 2400 *serious* games of Chess and lost only around 170 of these games. In 1989 he had played, and beaten, the computer program "Deep Thought." On February 10, 1996, playing as the reigning World Chess Champion, he lost a game of Chess to a computer, Deep Blue (Kasparov 1996), but still won the tournament. This date is significant for a number of reasons: firstly, and most widely known, for the first time (under normal tournament conditions), a computer program beat a top human player in a game which – until that day – was considered the ultimate benchmark for human versus machine intelligence (despite the game of Go being more complex). Far more importantly, however, is that Kasparov later claimed that during the game he "could feel" and "smell" a "new kind of intelligence across the table" (Kasparov 1996). What he meant was that the moves of his opponent bore witness to an intelligence that he, at the time, did not believe a computer could exhibit. It is not the superior play and triumphant victory at its end but the outstanding demonstration of insight and *intelligence* that makes *Game 1* of the 1996 "Deep Blue versus Garry Kasparov" match a turning point in the history of artificial intelligence. While Kasparov ended up winning the tournament (2–4), he had, arguably, conceded a win of the Turing test to Deep Blue. This test, famously proposed by Turing (1950), elegantly sidesteps the need to formally define the concept of *intelligence* before being able to assess it. It does so by suggesting that if the behavior of an opponent (as opposed to the physical appearance) could fool a human judge into believing that this opponent was human, then that opponent should be considered intelligent, independent of the embodiment of the intelligence. Arguably, in February of 1996, Deep Blue did just that.

In contrast, and despite being considered a "watershed for AI" (Hassabis 2017), when Deep Blue finally defeated Kasparov 1 year later in 1997 $\left(3\frac{1}{2} \text{ to } 2\frac{1}{2}\right)$, this constituted much less of a victory in the sense of the Turing test. This date is considered a "major success for artificial intelligence and a milestone in computing history" (Schaeffer and van den Herik 2002), but as Wiener wrote 37 years earlier, pure calculation is only a part of the process. One needs to consider the playing history of the opponent as well and be able to adapt to it accordingly during the game. In the case of Deep Blue, the machine knew every major game Kasparov had ever played while Kasparov was completely in the dark about Deep Blue's capabilities.

Of course one can argue that in 1996 this was true in reverse, as Kasparov (1996) himself acknowledged. He admitted that, after losing the first game, his defense "in the last five games was to avoid giving the computer any concrete goal

to calculate toward." He stated that he knew the machine's priorities and that he played accordingly; he closes by conjecturing that he has "a few years left." In fact, he had little more than a year before, on May 11th, 1997, Deep Blue won the deciding game of 6, thereby defeating the human world champion $3\frac{1}{2}$ to $2\frac{1}{2}$. The stronghold of human superiority and intelligence had finally fallen, and other landmark victories of AI were soon to follow.

Go: AlphaGo

Go has been described as the *Mount Everest of AI* (Lee et al. 2016b). This is fitting in the sense that it represents the highest peak we can climb but not necessarily the most difficult thing conceivable: Go is maybe the most complex game that is actually played by humans, with the number of theoretically possible games being in the order of 10^{700} (Wang et al. 2016) – a number expressing a quantity larger than the number of atoms in the universe (Lee et al. 2010). But if it was merely complexity we were after, harder challenges could easily be designed. However, it is also the fact that humans have engaged in playing Go for millennia and through this have reached high levels of mastery that makes it of interest to the AI community. In the context of squaring off humans against computers, Go is the likely candidate for the *ultimate* turn-based board game of perfect information.

From 1998 to 2016, competitions pitting computer programs against human players have been held every year at major IEEE conferences, with the handicap imposed on the human players dropping from 29 in 1998 to 0 in 2016 (Lee et al. 2016a). It is important to understand that the advantage gained from the handicap imposed on the human player is not linear in the size of the handicap. The handicap is implemented as stones the computer may place before the game starts; therefore, e.g., an advantage of 4 allows the computer to *claim* or *fortify* all four corners, while just one handicap (stone) less allows the human player to do the same for one corner, arguably allowing for entirely different game play (Lee et al. 2012), especially on a smaller (9×9) board. On a full (19×19) board, the step from a handicap of 4 to one of 3 was a massive one, and it was taken by AlphaGo in March 2016. Until then the reigning top computer program, "Zen" was only able to prevail against top professional players with a handicap of 4 (Lee et al. 2016b).

AlphaGo, created by DeepMind, entered the circuit around October 2015. It did not just capitalize on improved hardware and increased computational power; it was built differently and combined at least two successful techniques: Monte Carlo Tree Search (Cazenave 2017) with *Deep Learning* (DL) (LeCun et al. 2015). Technical details of DL are discussed in Clark and Storkey (2014), Gokmen et al. (2017), and Jiang et al. (2017). As the program played its top contemporary computer programs "Crazy Stone," "Zen," "Pachi," "Fuego," and "GnuGo," it proceeded to beat them all (winning 494 of 495 games with the single-machine version and triumphing in every single game with the distributed version) (Silver et al. 2016).

AlphaGo first beat the European champion Fan Hui 5 to 0 in September 2015 (becoming the first program ever to defeat a professional player) and within half a year proceeded to defeat the reigning human world champion Lee Sedol (who by some is "hailed as the greatest player of the past decade" (Hassabis 2017)) 4 to 1 in March 2016 (Fu 2016). It won the first three games, taking home a sweep victory (best of 5), but maybe more importantly it awed top human players, not unlike Deep Blue had awed Kasparov in 1996: commenting on the legendary move 37 in AlphaGo's second game against Lee Sedol, Fan Hui is quoted to have said: "[i]t's not a human move. I've never seen a human play this move, [. . .] So beautiful . . . beautiful" (Metz 2016).

Toward the end of 2017, AlphaGo Zero was introduced as the next incarnation of the system. It not only learned three games (Shogi, Chess, and Go) autonomously from scratch (Silver et al. 2017) but then proceeded to beat the top programs currently playing these games. In a way, AlphaGo Zero is not a program designed to play Go but a program designed to *play according to a set of rules*. More specifically, AlphaGo Zero can *at least* learn and play turn-based games of perfect

information without chance and has demonstrated its ability to play these games at the expert level.

As such, AlphaGo Zero might mark the end of this sub-area in computational challenges. We can (and will) surely continue to build better programs and let them play each other, but as far as the question of superior game play is concerned, humans have met (and created) their masters.

Poker: DeepStack and Libratus

Both Go and Chess are games of perfect information: all information about the game is known by both players at all times. *Zermelo's Theorem* (Zermelo 1913 – English version of the paper: Schwalbe and Walker 2001) states that deterministic (not based on chance) finite two-player games with perfect information [. . .] have a non-losing strategy for one player (i.e., either one player can, theoretically, force a win, or both players can force a draw). This means that – theoretically – one could calculate all possible versions the games of Chess and Go can be played and then simply never choose a move that results in a defeat. While this is practically impossible, due to the exceedingly high number of possible games, it means that for these two games – in theory – a machine could be built that would never lose a single match. Therefore it is only practical limitations that prevent computers from outperforming humans and all that it takes is clever algorithms that get around these limitations. That being said, actually achieving this has been considered a major achievement in the field (Jørgensen 2009) and by no means should the triumphs of Deep Blue and AlphaGo be belittled. As stated above, the defeating of the top human players in these games are landmarks in the history of artificial intelligence.

Heads-up no-limit Texas Hold'em, a popular version of the game Poker is considered the main benchmark challenge for AI in imperfect-information games (Brown and Sandholm 2017). In 2017, a Poker playing AI designed at Carnegie Mellon University (CMU), going by the name Libratus, prevailed against four top human players in a tournament and over the course of an aggregated 120.000 hands. Libratus became the first program to defeat top human players (Metz 2017). This victory has not come easy, as "Claudiro," an earlier program by the same team, failed in 2015. But while Claudiro was defeated, it was so only by a margin: after a combined $170 million had been bet, the humans were up by a mere 3/4 of a million (Tung 2015). Claudiro's performance, despite falling short of a decisive victory, indicated that Poker was not outside of what's possible. Within 2 years, its creators returned with Libratus, and another long-standing challenge in the field of artificial intelligence was met (Moravčík et al. 2017).

At the same time as Libratus was developed at the Carnegie Mellon University, another group at the University of Alberta designed DeepStack. By the time of Libratus' victory in early 2017, DeepStack had already competed in a tournament and won (in December 2016), with the resulting publication undergoing peer review. While DeepStack played 33 professional poker players from 17 countries, Libratus competed against four of the best human players in the world. Both programs showed a statistically significant superior performance over their human opponents (Riley 2017). DeepStack's performance exceeded the threshold of what professional players consider a seizable margin by a factor of 10 (Moravčík et al. 2017). Both programs approached the problem differently, which goes to show that the field of AI has not just chipped away at the (next) "last" stronghold of human AI, but it has done so in multiple ways, indicating that these victories were not achieved by machines capitalizing on human shortcomings but on progressively refining techniques which enable computers to improve their playing of the game.

Libratus is using a supercomputer at the Pittsburgh Supercomputing Center to build an extensive "game tree" to evaluate the expected outcome of a particular play. DeepStack instead uses a neural network to "guess" the outcome of a play, not entirely unlike how humans use "intuition" (Metz 2017).

Jeopardy!: Watson

In early 2011, a natural language question and answering program called Watson (named

after IBM's founder Thomas J. Watson (Brown 2013)) became world famous after winning the US TV show *Jeopardy!* (Kollia and Siolas 2016). This game show has been on TV since 1984 and revolves around contestants correctly identifying questions, on the basis of being given the resulting answers. The maximum time allowed is 5 seconds, and three contestants compete for being the first to correctly identify the question (Ferrucci 2010). Winning the game requires the ability to identify clues involving subtleties, irony, and riddles, and as such, the competition is firmly within areas where humans excel (and machines traditionally fail) (Brown 2013).

Over the course of 3 days, from February 14 to February 16, 2011, IBM's Watson proceeded to beat the two highest performing humans in the history of the game: Brad Rutter, who had been the show's largest money winner ever, and Ken Jennings, the record holder for the longest winning streak. Not only did Watson beat both humans, but also it utterly defeated them: in the end Watson had won in excess of $77,000 while its opponents combined won less than $46,000 (Ken Jennings $24,000 and Brad Rutter $21,600). The match was watched by close to 35 million people on TV and an estimated 70% of all Americans knew of the program (Baughman et al. 2014), making the program a bona fide celebrity.

Watson was the result of a 7-year project (Frenkel 2011), which resulted in a program that could interpret and parse statements made in often messy and colloquial English and search through up to 200 million pages of text to identify and generate the appropriate question (Strickland and Guy 2013) for the answers provided. For years to come, it was considered one of the leading intelligent systems in existence (Abrar and Arumugam 2013). IBM itself has claimed it to be the first software capable of cognitive computing (Holtel 2014) and considered its creation and victory at the game show the beginning of an "Era of Cognitive Computing" (Kelly and Hamm 2013).

The expert systems of the early years of artificial intelligence were systems that were designed to reason using learned (hard coded) steps. This process had to be painfully constructed on the basis of the testimony of human experts. In contrast, Watson uses probabilistic methods that result in *confidence* scores for answers (Ahmed et al. 2017). Due to this, the program is able to attempt answers to problems it has never seen before, i.e., it can operate under incomplete or missing information (Gantenbein 2014).

One more thing sets Watson apart from the computer programs mentioned before and their landmark victories: while being built to compete and win in the TV show *Jeopardy!*, the 3-day competition that made it famous was only a first step in its (intended) career. IBM considered the game show a real-world challenge in the area of *Open Domain Question Answering* (Ahmed et al. 2017), but winning against a human was a means to an end, not the goal. The ability to perform on human levels when subjected to open domain questions demonstrated for the first time that a program could engage in such an activity, independent of the setting or context. From the start Watson's creators had more in mind than merely winning a game show (Baker 2011). In what IBM has called *cognitive computing* (Kelly and Hamm 2013), the ability of programs to learn from experience and understand problems that were so far firmly in the domain of humans (Asakiewicz et al. 2017) has the potential to disrupt virtually all aspects of our lives, with all the commercial implications and opportunities that come with it.

The nonlinear increase in data generation, storage, and processing in recent years has arguably ushered in a new age, one where intelligent data analytics and text analysis (Cvetković et al. 2017) are rapidly increasing in relevance. The technology behind Watson has been applied to the domains of, e.g., legal services, health care, banking, and tourism (Gantenbein 2014; Murtaza et al. 2016). Of those, applications in the domain of health care constitute the largest benefit to society due to their societal importance (Kelly and Hamm 2013) and reliance on (massive amounts of) data (Ahmed et al. 2017). The exceptional performance exhibited during the game show, especially with regard to natural language processing and under the added challenge of colloquial speech,

ambiguity, and *reading between the lines*, has made it clear that the true calling for systems like Watson may be found outside the studio and in our daily lives (Kelly and Hamm 2013).

Philosophical Thoughts

Intelligence is a concept humans are very familiar with yet to date have failed to define well. Part of the reason why the Turing test is still relevant is because it sidesteps this dilemma by using the one definition human can agree on: human intelligence. If a human can be fooled to believe an opponent is human, then it must exhibit human-like behavior and, in this case, intelligence.

All games discussed above are landmark games in the area of artificial intelligence, but they are neither painting a complete picture nor are they the only ones that have been a key game for machines to compete against humans. One obvious example is the game of *Soccer*, where entire leagues of various machines compete for titles. In this entry, we entirely ignore the physical aspect of games and therefore all games that require physical behavior. The motivation for this is twofold: on one hand, the progress made in this area is equally stunning and pervasive, with new results and achievements being showcased in videos regularly. Providing a fair overview over these achievements is firmly outside the scope of this entry (the interested reader is invited to search for YouTube videos of, e.g., *Boston Dynamics*). On the other hand, this entry considers the term *intelligence* only in the intellectual sense and not in the context of mastery of the physical domain.

For millennia the mastery of certain games, often based on exceedingly simple rules, was seen as the pinnacle of human intelligence. Chess was considered an object of intellectual skill (Jørgensen 2009) and diversion (Spencer 1975). Professional Go players are known to describe promising board configurations as *esthetically pleasing*. In 200 BC, poetry and Go went hand in hand in Japan (Smith 1956). The complexity of games can extend far beyond what humans can consciously grasp and explain; many top players play games partly *intuitively*, that is, with a clear understanding of which moves they prefer but without the ability to justify this preference.

In the final years of the last millennia, this stronghold of human intelligence came under attack. While futile promises made by the most prominent experts in the field of artificial intelligence (e.g., Herbert Simon's "a computer [will] be the World Chess Champion before 1967" (Hsu et al. 1995)) have demonstrated time and time again that the advent of AI is not, by far, as sweeping and complete as they hoped, it seems inevitable and unstoppable.

In this context, it is important to remember that these are *just* games. These are controlled environments with often very clearly stated rules (Naddaf 2010). In addition and maybe far more importantly, these are interactions in which the evaluation of an outcome is clearly defined and often one-dimensional (i.e., win vs. loss). Real life is of a different complexity, and humans do not share the same views on how outcomes are evaluated. Artificial intelligence may be able to outperform humans in any one subject, but the true benchmark for intelligence may be a matter of defining the meaning of the concept *intelligence* for us. Machines are bound to be faster and more precise than humans; there should be no surprise about that. Whether they can be better at something than humans is really a question that cannot be answered until we know what *better* means, in the respective context.

One thing is becoming painfully obvious: we are running out of games to have computers beat us at. Maybe the age of game-playing AI is coming to an end. Or maybe the games need to change, and *winning by points* is no longer the victory we prize the most. Cooperative game play, with teams of humans and AI players working together, might be a new challenge in the years to come. In the end, when one has mastered a game to perfection and is guaranteed to never lose a match, *the only winning move is not to play.*

Cross-References

- Computer Games and the Evolution of Digital Rights
- Computer Games in Education
- Computer Go
- Genetic Algorithm (GA)-Based NPC Making
- History of Virtual Reality
- Machine Learning for Computer Games
- Monte-Carlo Tree Search
- Overview of Artificial Intelligence

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Computer Games and the Evolution of Digital Rights

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Synonyms

Video games; Digital games; Intellectual property; Intellectual property rights; Commercial rights

Definition

Computer games are all games that are played using a computer to display the board, generate events, and provide other players to play with or, generally, for any other game relevant aspect. The *entertainment industry* is a wide term to encompass any business generating profit from their activities related to the entertainment sector.

Introduction

The MITS Altair 8800, released in 1975, is often considered to be the first true personal computer (Wolf 2008). Its operating system was created by two guys from a young company (then still called "Micro-Soft") who offered it as a product to MITS before they had actually written it. These young men (Bill Gates and Paul Allen) soon went on to also sell IBM an operating system (MS-DOS, written in 8086 assembly) for their x86-based computers. While this does not mark the first time that hardware and software became two separate products, it is arguably the most famous one as the renamed company, *Microsoft*, went on to become a giant of the industry. While there are many fascinating aspects to the time and these companies, the fact that MS-DOS already used hidden and undocumented features to disrupt competitors' products (e.g., later MS software products would not work correctly unless the computer was running on MS-DOS – as opposed to their competitors' version of DOS – as its operating system) is the most relevant here.

Ever since then, the industry has kept changing its business models (Ojala and Tyrvainen 2011) and how to protect them. Computer games are a good product family to illustrate and discuss this. They are by many considered an essential part of the software and entertainment industry (Hildmann and Hildmann 2012), but one that is historically understudied (Saarikoski and Suominen 2009). There is no comprehensive analysis of the history of video and computer games from a business point of view (Royer

2011), yet. For a general account, we refer to, e.g., Purcaru et al. (2014) or Dillon (2016).

Computer Games Driving the Hardware Industry

Wolf (2008) and others say that it was the computer games that (financially) drove the evolution from computers the size of warehouses to the PC; from the 1975 MITS Altair 8800 to whatever model and type is considered state of the art at the time the reader is reading this. Whether computer games alone deserve the credit for this transformation, which is at the heart of the communication and information revolution of the last decades, is arguable; whether computer games have become (and been for 40 years now) a best-selling product is not a question at all. In the entertainment industry, they have long since replaced traditional board and card games in overall profit (Bohannon (2008) estimated gaming to be a $11 billion industry globally in 2008; in 2016 this is the economic impact of the gaming industry to the US GDP alone (Anderton 2017)) with the global industry exceeding $90 billion (https://tinyurl.com/ya7tfobf (venturebeat.com)).

The next paragraphs will sketch the century-long development from Charles Babbage's Analytical Engine early in the nineteenth century (Spencer 1975) to the video game culture of today (Kushner 2011; Williams 2017).

From the Arcade to the Living Room (The Rise of Atari)

This pervasive euphoria for computer games was not always the case. For example, the 1958 game *Tennis for Two* did not receive wide public attention or marketing (Nyitray 2011). Until 1972 commercial computer games came only in the form of arcade games, sold by companies like Midway, Bally, and Atari (Mazor and Salmon 2009). While Magnavox found itself selling its analog home TV game *Pong* in respectable numbers, they decided to shift their business paradigm from selling the consoles to selling the games (i.e., introducing different ROM cartridges that would all run on the same console). As far as home consoles are concerned, Ralph Baer's television-based *Brown Box* (1966–1967) and *Magnavox Odyssey*, released in 1972 (the year of *Pong*) (Montfort and Bogost 2009), are considered landmark hardware when it comes to lineage and impact on design (Nyitray 2011). Three years later, in 1975, Atari started building arcade games for the private use (Wolf 2008), i.e., home versions. These consoles included *Pong*, but as they were basically stand-alone units, built on a game-by-game basis, production took a long time and was very costly. In October 1977 Atari released the VCS (Video Computer System) 2600, which could be fed with cartridges of individual games. This product did well and ultimately became the most successful of the early game consoles (Royer 2011). However, financially speaking, it did not do well enough in its initial years. The 1978 arcade game *Space Invaders* (by Tomohiro Nishikado), which was licensed by Atari for the home market, partly rescued them from the losses of 1977–1978 (Montfort and Bogost 2009). Historical reviews such as Glenday (2009) rank the game as the top arcade game ever, and its arcade version famously caused coin shortages in some countries. The game's 1980 VCS release is considered to have multiplied Atari's console sales.

Digital Rights (The Fall of Atari)

What became Atari's final mistake was that they did not protect their developmental investment into the consoles. At the time a shift in the business model happened, in the sense that the profit did not come from the sales of the consoles themselves anymore but from the subsequent sale of individual games. Unfortunately (for Atari), the only protection against *some guys in a garage* starting to write their own games was the fact that Atari did not offer a programming manual or the console blueprints to just anyone.

According to (Levy 2010), Atari *"regarded the workings of its VCS machine as a secret guarded somewhat more closely than the formula for*

Coca-Cola." So when Activision was formed in 1980 (Royer 2011) by some of Atari's best coders gone rogue, it marked the eventual end of Atari's unprecedented success (and the console industry as a whole), simply because the soon increasing number of game-producing companies did not have to pay any royalties for the use of the consoles on which their games were being played. As O'Donnell (2009) states, *"[a]ny company capable of determining how the 2600 worked and willing to pay for the cost of producing cartridges could then market their games, which set a low bar for quality."* This raid on the profit of the console-producing companies (bearing the full financial burden and risk of providing the platform for the games) combined with the sudden flood of mediocre games (which both disappointed the consumer as well as caused the dumping of prices) let to the collapse of the industry in 1983 (Royer 2011). The age of Atari lasted a mere 6 years, but it turned a generation of kids into computer game players, computer (game) programmers (Aspray 2004) and, eventually, computer scientists. The credit for doing this does – of course – not go to Atari alone; the company is mentioned as one (admittedly very dominant and rather famous) example of what today is a global multibillion dollar industry.

Copyright Protection and IPR (From Nintendo to Today)

It took another 2 years and another company to bring about a change in the market. Nintendo's introduction of the Nintendo Entertainment System (NES) (A number of NES games are emulated and playable online at http://www.virtualnes.com) in the winter of 1985 became a turning point in the history of the industry (O'Donnell 2009) and even has implications for the Digital Millennium Copyright Act (DMCA) of 1998. The system required an *authorization chip*, the 10NES, to be present in the cartridge. Atari tried unsuccessfully to reverse engineer the chip and even went as far as to physically disassemble the chip (to no avail). The introduction of this chip is considered the moment when the industry changed from protecting its hardware to protecting copyright. Since the chip was required to be in the cartridge in order for the game to work in the console, preventing the chip from being copied meant to control the games that could legally be sold for a console. It is noteworthy that the design of the 10NES chip was integral to this, as the similar approach taken by SEGA failed. Accolade, who had reverse engineered the SEGA system to be able to circumvent it and publish games for the Genesis III, ended up winning a court case against SEGA (O'Donnell 2009).

There are a few differences between the protection mechanism for the NES (by Nintendo) and the approach taken by SEGA to protect their Genesis III:

1. Instead of a special chip such as the 10NES, SEGA relied on the string SEGA being found at a specific position in the memory of the game cartridge. Writing this string to correct location in memory required the knowledge of *what* to write *where* but did not require a specific (and protected) chip.
2. In addition, when the string was present on a game cartridge, SEGA had its game console display the text *"Produced by or under license from SEGA Enterprise LTD"* before starting the game. This, however, meant that anyone using the game including the string without permission (i.e., payment of royalties to SEGA) effectively infringed on SEGA's trademark.
3. Finally, as the string in memory was originally written by SEGA, copying it could be considered a breach of the copyright of SEGA's code.

While the initial ruling was in favor of SEGA, Accolade successfully appealed and subsequently won the case, with one of the arguments being that the string in memory was tiny in comparison to the amount of code written for the actual game and that the copyright breach was therefore negligible. In addition, the clever use of SEGA's trademark as a copy protection mechanism was ruled to constitute a violation of certain legal restrictions placed on the use of trademarks. Since then, the industry (computer games and the computer industry in general) has continuously changed to ensure the

protection of the companies' investment into intellectual property (mainly the software).

Summary and Conclusion

According to Ojala and Tyrvainen (2011) over the last decade, the software industry has taken the shape of a $200 billion software division within a $500 billion service industry. Even the latest offline digital rights management (DRM) tools, such as Denuvo (https://www.denuvo.com/), fail to adequately protect against piracy. One famous example of this is the case of *Resident Evil 7* in 2017 which was cracked within 5 days (https://tinyurl.com/yaaluusm (www.dsogaming.com)). Additionally offline DRM systems can have impacts on the performance of a game (http://www.sega.com/denuvo) and even block paying customers. This leads to two approaches by the industry: either a complete move away from DRM as done by CD Projekt Red's gaming platform *Good-Old-Games* (https://www.gog.com) or the move to a cloud-based DRM as done by Valve's platform Steam or others. Tommy Refenes (Super Meat Boy developer) states *"the fight against piracy equates to spending time and money combating a loss that cannot be quantified"* and *"[d]evelopers should focus on their paying customers and stop wasting time and money on non-paying customers."* While cloud-based online DRM systems made it harder to make illegal copies of software (and, as Ojala and Tyrvainen (2011) point out, specifically games), they can also lead to a loss of reputation and customers. While Steam managed to introduce a semi-online DRM (allowing for up to 4 weeks in offline mode) and still be considered a positive influence for PC gaming by providing additional services (https://tinyurl.com/ycp4c9be (www.cinemablend.com)), others have failed here. For instance, Ubisoft's original always-on DRM leads to some backlash from the customers especially when the servers for the DRM are not reachable (https://tinyurl.com/y97alctv (kotaku.com)). In this case it leads to a switch in the company policies removing the always-on demand for single-player games (https://tinyurl.com/yb8w795f (www.rockpapershotgun.com)).

Cross-References

- Computer Games and Artificial Intelligence
- Computer Games in Education
- Gamification and Serious Games
- Gamification
- History of Virtual Reality
- Overview of Artificial Intelligence
- Serious Online Games for Engaged Learning Through Flow
- Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

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Computer Games for People with Disability

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Synonyms

Auditory impairment; Autism; Cerebral palsy; Down syndrome; Dynapenia; Dysgraphia; Dyslexia; Dyscalculia; Intellectual disability; Learning disability; Motor disability; Rehabilitation; Sensory disability; Visual impairment; Visual memory; Zika virus

Introduction

A computer game for people with disability may be for people with a sensory disability, motor disability, intellectual disability, learning disability, weak communication skills, weak social skills, or a combination of these. This chapter is a concise survey which includes representative games for each category of disability. Games addressing disorders that do not fall in any category of disability are not in the scope of this survey. The goal of the survey is to make the readers aware of the types of disability for which computer games have been developed. It does not include work at the intersection of games and disability which primarily falls in any of the following categories: (i) identifying design considerations or requirements using interviews, questionnaires, or data collected from gaming sessions without emphasis on specific games; (ii) platforms, architectures, or frameworks for creating games; (iii) interfaces or controllers for games; (iv) using hardware and software such that gamification is very limited, like use of stars to motivate the player; (v) game proposals, standards, or designs that are not implemented or evaluated; (vi) games which were either not evaluated or whose evaluation did not involve healthy subjects, subjects with a disability, or specialists; (vii) factors affecting acceptance of games; (viii) games for training members of educational or medical staff, such that these games are not designed to be played by people who need to be evaluated to see if they have a disability or disabled people who need to be treated; (ix) educational apps with very limited gamification; (x) challenges in design, development, or evaluation of games; (xi) automating or improving fulfillment of tasks in design, development, evaluation, customization, localization, or enhancement of games; (xii) reporting on digital-game-related resources or their strengths, weaknesses, or limitations; (xiii) use of disability-inspired games to serve areas other than disability; (xiv) comparison of digital games with other forms of education or entertainment; and (xv) digital games for helping people with a disability get familiar with assistive technology.

Games for People with Sensory Disability

Most computer games for visually impaired players give them feedback using audio, haptics, or enhanced imagery. Most computer games for hearing-impaired players give them feedback using a sign language. Moustakas and others (2011) report on a framework for real-time communication between visually impaired and hearing-impaired game players in a shared environment, along with experimental evaluation.

Their framework uses gesture recognition, sign-language analysis, sign-language synthesis, speech analysis and synthesis, and haptic interaction. Visual information about the gaming environment is conveyed to the visually impaired player via haptic interaction. Semantic information about the gaming environment is conveyed to the visually impaired player using sound. Verbal input from the visually impaired player is perceived using speech recognition. Sounds of musical instruments are used to enable the perception of colors using the SeeColor utility. Verbal information is presented to the hearing-impaired player using sign language. The hearing-impaired player can provide input to the system through the sign-language recognizer. The framework communicates the visually impaired player's input to the hearing-impaired player by recognizing the former player's speech and synthesizing signs for the speech for the latter player. The framework conveys the hearing-impaired player's input to the visually impaired player by recognizing the former player's signs and synthesizing speech for the signs for the latter player. When the visually impaired player touches a virtual object, he/she hears the sound synthesized for the object's color. Training is needed to help visually impaired players link colors with sounds. The visually impaired player and the hearing-impaired player play the game cooperatively, with the odd-numbered steps played by the visually impaired player and the even-numbered steps played by the hearing-impaired player. Translation between speech and signs occurs via text. Speech is translated into text and the text is used to generate signs. Signs are translated into text, and speech consistent with the text is generated.

Lanyi and others (2011) have reported on several serious games for people with learning disabilities and sensory impairments. A very small percentage of such people have jobs. *Cheese Factory* (Lanyi et al. 2011) is a game which teaches the concepts of fractions and percentages. *My Appearance* (Lanyi et al. 2011) is a game involving morning tasks that are typically completed after getting up and before leaving home. *3D Work Tour* (Lanyi et al. 2011) is a game which simulates the first days at a workplace. *VR Supermarket* (Lanyi et al. 2011) is a game which teaches shopping and money management during shopping using a shopping list, shopping cart, shelves with goods with their names, prices, and images, and a virtual wallet containing banknotes and coins. *Memobile* (Lanyi et al. 2011) is a game involving important tasks that are typically performed before leaving the house and throughout the day, e.g., packing lunch, taking money, and taking medications. *Stress at Work* (Lanyi et al. 2011) is a game which educates on stress at work. These games were evaluated by people from three countries who specialized in psychology, children with special needs, and IT administration.

Martinez and others (2019) report on SATReLO. It is a tool which allows construction of personalized mini-games for helping children with loss of hearing speak a language and write in a language. A therapist can select the language attributes (articles, pronouns, nouns, objectives, and verbs) to be included in the mini-game. The therapist can also select the theme of the mini-game. The theme can be animals, school supplies, or professions. *Domino* and *Sequence Cartoon* are the mini-games that SATReLO allows a therapist to customize. Some of the children used in the evaluation of SATReLO had a cochlear implant or a hearing aid. The rest had normal hearing.

A baby infected with Zika virus before birth may have a smaller head, joints with limited range of motion, seizures, and problems in vision and hearing (https://www.cdc.gov/zika/healtheffects/birth_defects.html). Filho and others (2020) report on a platform for evaluating executive functions of toddlers and training them. This study included 18 toddlers born with Down syndrome and 16 toddlers born with Zika virus. Let's Smile (Filho et al. 2020) is a game which shows sad white faces which become smiling colorful faces when touched. Let's Blow the Balloon (Filho et al. 2020) is a game which shows colored withered balloons tied to a string. The player is expected to keep the button below a balloon pressed, to fill the balloon with air. The balloon expands until it touches the top of the screen. When the balloon cannot be inflated anymore, the player is expected to move the finger away from the button that was

pressed for inflation, and touch the balloon to pop it. The assessment criteria for Let's Smile included proportion of hits without repetitions, and proportion of precision without error. The assessment criteria for Let's Blow the Balloon included holding time and reaction time.

Games for People with Motor Disability

Burke and others have reported on virtual-reality games and webcam games for post-stroke rehabilitation of upper limb (Burke et al. 2009). *Catch* (Burke et al. 2009) for bilateral rehabilitation requires the player to move a physical basket with magnetic sensors attached to it, to catch objects falling in the virtual environment which has a virtual basket. *Whack a mouse* (Burke et al. 2009) requires the player to move a hand with a sensor attached, to hit the mouse in the virtual world with a virtual hammer, in the first level of the game. Mouse and dog appear in the second level of this game, but the player should not hit the dog. This is for improving the player's visual discrimination and selective attention. *Rabbit Chase* – a webcam game (Burke et al. 2009)– is for rehabilitation of one arm. There is a rabbit which moves between four holes and the player must touch the hole with the rabbit when the rabbit stares from it. *Arrow Attack* (Burke et al. 2009) is a webcam game for rehabilitation of both arms. The player should touch the right arrow when the right arrow reaches the right box, using the right hand. The player should touch the left arrow when the left arrow reaches the left box, using the left hand. Burke and others (Burke et al. 2009) also report on a game which allows the player to play a *virtual vibraphone* – an instrument like xylophone, through remote controllers. This game is for rehabilitation of wrist and arm.

Hernandez and others (2014) present Liberi – a networked, cycling-based game – to help youth with motor disabilities socialize while being on special recumbent stationary bicycles. Players pedal to move their avatars. A player aims using a joystick and invokes game actions with one button. Liberi consists of six mini-games. Players are grouped fast since their avatars just have to stand on a launch pad and one player has to press action button on game controller to form their group. Voice links to other players are established immediately. Players can join a mini-game in progress by standing on its launch pad and pressing the action button. All avatars move at the same speed despite the differences in pedaling speeds. This avoids skill-based segregation of players. Some of the mini-games have goals only for group of players, and all players get the same reward when their group achieves its goal. Ten youths with cerebral palsy, including seven boys and three girls, played the mini-games from their homes over 10 weeks. On average, each player spent 2.75 h/week playing Liberi. All players spent the majority of the time playing with others when at least one other player was available. This showed that Liberi was successful in promoting group activities among the players.

E-Wobble (Karime et al. 2011) is an interactive rehabilitation system for stroke survivors who are unable to raise the foot at the ankle. The system includes a plastic wobble board, an accelerometer, vibration motors, a microcontroller, a wireless communication module, a sensorized sandal on top of the board, and a two-dimensional digital golf game with which the wobble board interacts. The sandal has cushioning in the area for the toes, with a pressure sensor placed below the cushion to detect the force exerted on it. The player has to move his/her ankle to move the golf ball. The player has to exert pressure on the cushion by flexing the toes, in order to drop the ball into the hole.

Zavala-Ibarra and Favela report on design and development of video games played with a custom-designed interaction device, to assist in detecting the early signs of dynapenia which is age-related loss of muscle strength and power (Zavala-Ibarra and Favela 2012). The interaction device contains Vernier Hand Dynamometer to measure the user's grip strength. One game requires the player to throw a ball. The player is given feedback about the amount of strength used by them. Another game allows the player to increase the altitude and the speed of the bird by pressing the controller. The third game asks the player to perform a maximum voluntary

contraction using the dynamometer and then maintain their force for as long as possible. The time elapsed between the start of application of the maximum force and the drop to half of the maximum force is the *muscle fatigue resistance*. The player is able to make the fire-extinguishing vehicle hold the water longer by retaining the force applied.

Dysgraphia is a nervous-system problem affecting fine-motor skills, causing handwriting to be consistently distorted or unclear (https://www.webmd.com/add-adhd/childhood-adhd/dysgraphia-facts). Kariyawasam and others (2019) report on a game-based screening-and-intervention tool for dysgraphia, dyslexia, and dyscalculia. Children in their study wrote Sinhalese letters on a mobile screen with a pen. Some of these children had *letter dysgraphia*. Children's writing was used as data for machine learning. A neural network and support vector machine (SVM) were used. Children predicted to have letter dysgraphia can be initially trained to write letters correctly by showing them animations to help in following the given paths. Children are allowed to write independently in later stages of intervention. Children were asked to write the 10 integers ranging from 0 to 9, for getting data for using machine learning for diagnosing *numeric dysgraphia*. The authors used a Random Forest classifier to predict if a child had numeric dysgraphia or not. Children predicted to have numeric dysgraphia can use animations to help in tracing the given numbers.

Games for People with Intellectual Disability, Weak Communication, or Weak Social Skills

Isasi and others report on a game about healthy eating which is playable on an iPad (Isasi et al. 2013). The game is intended for 8- to 12-year-old children with Down syndrome. The game consists of two mini-games. The first mini-game requires the player to iteratively select ingredients to make a salad. The player is shown two ingredients on each iteration, such that only one of them is suitable for salad. The second mini-game requires the player to choose foods to create a well-balanced breakfast.

Wyeth and others (2014) report on Stomp-a floor-based system requiring simple gross-motor actions. Stomp is designed for people with intellectual disability. Players interact with the digital worlds by triggering the pressure sensors embedded within a floor mat. There are interactive experiences that are projected onto the mat. Stomp can be used by one or more people, by stepping, stomping, pressing, jumping, or sliding. Players stomp on icons to make their selection. The experiences provided by Stomp included three musical experiences, three sports experiences, a painting experience, a paddling experience, a road-safety game, a sheep-herding game, and four arcade-like experiences. Players can interact with Stomp while sitting, standing, walking, or lying down. They get visual and auditory feedback. Stomp promotes physical and social activity. People with cerebral palsy, communication disorders, mental retardation, autism, or Down syndrome, used Stomp.

Hassan and others report on a game to teach usage of money to 9- to 14-year-old autistic children (Hassan et al. 2011). The game teaches children to recognize banknotes and choose correct banknotes for purchases. The game also includes communication with the shopkeeper to teach social skills to children.

Games for People with Learning Disability

There are differences between intellectual disability and learning disability. A person with an intellectual disability faces challenges in more than one area. These areas include communication, completion of activities of daily living, learning, speaking, memorizing, foreseeing, and physical movement. A person with a learning disability may face challenges in one or more areas of learning. Dyslexia is a learning disorder that affects the ability to read, spell, write, and speak. (https://www.webmd.com/children/understanding-dyslexia-basics). Dyscalculia is a brain-related condition which makes basic arithmetic hard to

learn (https://www.webmd.com/add-adhd/childhood-adhd/dyscalculia-facts). Kariyawasam and others (2019) used a Convolutional Neural Network, KNN (K-Nearest Neighbors algorithm), and audio clips of children's pronunciations of words and letters to predict if children were dyslexic. They report on a multisensory gaming environment to offer intervention for children predicted to be dyslexic. The hard stage requires the child to pronounce the displayed word. If the child pronounces the displayed word correctly, the balloon bursts, and the child is congratulated by the gaming environment. These authors used the gaming environment to let children show their ability to count numbers, compare numbers, and add numbers. The authors used counting accuracy, time spent per counting question, number-comparison accuracy, time spent per number-comparison question, addition accuracy, time spent per addition question, and an SVM (Support Vector Machine) classifier, to predict if a child was affected by dyscalculia or not. The gaming environment is used to offer intervention to children predicted to have dyscalculia.

Visual memory is the ability to immediately recall what the symbols, shapes, objects, or forms just seen by eye looked like. Visual memory is important for processing short-term memory into long-term memory (https://www.optometrists.org/vision-therapy/guide-vision-and-learning-difficulties/guide-to-visual-information-processing/visual-memory/). A person can have poor visual memory despite normal vision and hearing. Pir and others (2019) report on Neuroland which is an application containing 10 digital mini-games for improving visual memory. Each of these games except two shows letters, words, shapes, or ships, and expects the player to select an option containing all of what was just shown, containing none of what was just shown, containing a color not present in what was just shown, containing a suitable subset of what was just shown, has color of what was just shown, or is of shape identical to the shape that was just shown. Words Chain displays some words for a few seconds, removes them from the screen, and expects the child to say them in the order in which they were displayed. Fish Aquarium displays aquariums with one fish in each. All fish differ in size. The child is expected to remember the size and location of each fish. Then fish are removed and aquariums without fish are displayed. The child is expected to select the aquariums sequentially such that each aquarium selected earlier had a fish that was smaller than the fish in every aquarium selected later. The study reported in (Pir et al. 2019) involved 24 8-year-old girls and 24 8-year-old boys. Of these, 12 girls and 12 boys were included in the experimental group and the remaining 24 children were put in the control group. The experimental group received intervention using Neuroland. The control group did not receive any intervention. The results showed that these mini-games were significantly effective in enhancing visual memory and writing skills.

Games to Promote Awareness of Disability

Gerling and others (2014) report on four mini-games that the player needs to successfully play to arrive at the party. These games are played by a person in a real wheelchair such that movements of the wheelchair control movements of the digital character. These mini-games are designed to make people not using wheelchairs aware of the challenges faced by users of wheelchairs and promote empathy toward them. One mini-game requires the avatar to cross the street while being in a wheelchair when the avatar arrives at an intersection. Another mini-game requires the avatar to find the items on the shown list while avoiding puddles inside a grocery store, and move the arm to reach the items. Another mini-game requires the avatar to pick items from a bookstore with multiple floors, using elevators instead of escalators. The arm needs to be used to grab items. Cake, cream, and candles are examples of items to be picked from the grocery store. Birthday cards and wrapping paper are examples of items to be picked from the bookstore. *Park* – one of the mini-games – requires the avatar to come to a park and get three flowers. The avatar must avoid stairs. After completing the four mini-games, the player navigates the streets to arrive at the friend's

house for the birthday party. Twenty-one females and 19 males participated in this study.

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Computer Games in Education

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Synonyms

Game-based learning (GBL)

Introduction

Computers have been used to create and play games for basically as long as they are around; according to Nyitray (2011), the first publicly accessible computer games appeared as early as 1958, though the term *game* might be rather grande for some of the early games. The game *Pong*, considered by many as *the first*, famously consisted of the moving of a bar on one side of the screen to deflect a moving dot (i.e., a ball) back to the other side of the screen, where another player attempted to do the same. There is evidence that traditional board games such as *Checkers* were

developed (Jackson (2000) and *Tic-Tac-Toe* was implemented (Egenfeldt-Nielsen et al. 2008) as early as 1951. One of the motivation for using the then new computing paradigm for such a mundane thing as playing a game was to *"convey the message that our scientific endeavors have relevance for society"* (Nyitray 2011).

While many maintain that games do not seem to serve any cultural or social function other than to distract (Bogost 2007), we argue in this entry that there is evidence to the contrary. There is little doubt that games can be beneficial, if used correctly and by trained exerts. In fact, there is a vibrant and fast growing community of researchers and practitioners in the field of games-based learning (de Freitas 2011). That being said, it is important to consider the evidence from established fields such as psychology and pedagogics to ensure that the dangers and shortcomings of the games-based learning industry – which today is a billion dollar industry – are not to be overlooked. As it is to be expected for a relatively young field which promises many business opportunities, there are many projects that seem to take short cuts. Of course the use of computer games alone is not the end to all problems in pedagogics; professionals and researchers in the field have emphasized (e.g., Hildmann 2010) that computer technology, while showing a lot of potential and offering many benefits, is merely a tool for a teacher.

This entry provides the relevant background on long established fields such as pedagogics and developmental psychology. The aim is to inform the those interested in designing, implementing or using computer games for educational purposes and to highlight the potential benefits of doing so. However, the main message is that such games are a supporting technology, and not the dominant factor or even the core aspect to teaching endeavors.

Computer-Games Based Learning

Rowland and Gardner (1971) date the use of computers (and in a way, computer games) for educational purposes back to 1956 (Ricciardi et al. 1957). In this context, we will use the definition offered by Connolly and Stansfield (2007), who have suggested that computer (games)-based learning should be seen as *"the use of a computer (games) based approach to deliver, support, and enhance teaching, learning, assessment, and evaluation"*. When used appropriately, this means combining.

Validated approaches from pedagogics, known models from psychology and learning theory as well as adhering to best practices for the design and implementation of computer games and intelligent user interfaces.

If this is done correctly computer games have the potential to constitute a platform through which the experts can deliver their teaching in a way that makes use of all the befits while mitigating a number of normal human traits (such as e.g., waning attention and lack of motivation).

But the use of games for non-recreational purposes (i.e., as *serious games*) is certainly not new (consider that every maneuver is, in a way, a game and the literature on military maneuvers is more than 2000 years old, e.g., Tzu and Cleary 1988), nor is it restricted to education (Puschel et al. 2010): *business games* have been proposed for research as early as the 1960s (Babb et al. 1966) and 1970s (Rowland and Gardner 1971). Games have been used to great success to train complex problem management (Pasin and Giroux 2011) problem solving abilities (Christoph 2006) as well as practical and reasoning skills (Pee 2011). When used appropriately they can significantly reduce training time and demands on the instructor (Sandberg et al. 2001; Hildmann and Hildmann 2012a, b). In fact, (computer) games have been analyzed from a variety of perspectives, both negative (e.g., aggression, violence or gender stereotyping) and positive (e.g., skills development, engagement or motivation) (Connolly et al. 2008).

Games-Based Learning (GBL)

There are many positive aspects of the use of games for teaching in the literature. Arguably, games have never been *just* a children's medium

(Bogost 2007) and are generally something in which people of all ages engage in (Warren et al. 2011). Games have been shown to inherently drive high motivation levels in those that play them (Malone and Lepper 1987). Repetition is a core element to many games, which can be used to embody otherwise boring rehearsal tasks and e.g., large firms and companies have used game-like settings for decades to implement training session for employee training activities. The literature lists many areas where games have successfully been used as training and simulation tools: military training (Schneider et al. 2005), teaching exact sciences, specifically mathematics (Habgood 2007; Squire et al. 2004; Young and Upitis 1999), training in software engineering and computer science (Ford and Minsker 2003; Zhu et al. 2007) as well as medicine (Beale et al. 2007; Lennon 2006; Roubidoux 2005). Other fields where GBL has been applied are language education and project- and knowledge management (Johnson and Wu 2008; Rankin et al. 2006; Long 2010) and Christoph (2006); Chua (2005), respectively).

This indicates that for members of a society to engage in playful activity has the potential to significantly influence the later performance of individuals as well as entire groups. Every military maneuver (Giles 1974; Leonhard 1994) or every play-acting of, e.g., household situations – as often performed by children – can be seen as a game with educational content.

When investigating the aspects that are credited with making a gaming experience *fun*, many parallels are found with what researchers such as Gee (2003) and Tiotuico et al. (2008) think makes for a good learning experience. This is consistent with insights from psychology which have long since accepted that the playing of games is an important factor in the early development of children and young adults. Bruce (2004) showed that the act of playing during childhood can strongly impact social behavior later in life. Green et al. (2010) report on research that indicates that playing action video games can have a beneficial impact in decision making.

As far back as the 1970s, games have also been considered in the context of serving as a platform for research projects, e.g., Cohen and Rhenman (1961) or Rowland and Gardner (1971) and Babb et al. (1966) report on investigations on using management games or business games (respectively) for research. In recent years a number of conferences and academic circles have focused on this subject and the field is rapidly growing. Today, the teaching and learning paradigm is no longer restricted to human-human interactions: advanced research is now considering knowledge transfer between humans and machines (from the former to the latter) and e.g., Arsenio (2004) reports on using simple games to assist humans when teaching robots.

Key Concepts of (Computer) Games-Based Learning

The behavioral activity of engaging in *play* is considered by e.g., Brown (1998) to be a fundamental basis for development in complex animals, on par with the act of sleeping and dreaming. As mentioned above, it is considered a significant help for the process of maturing from children to fully rounded adults and a strongly determining factor in the shaping of a functioning member of society (Bruce 2004). Specifically, video games are said to have a unique persuasive power and to have the potential to support existing social and cultural positions (Bogost 2007). They can maintain high motivation levels and seem to center around a number of fundamental principles (Malone and Lepper 1987). We briefly discuss intrinsic motivation attributed to games and identify a number of key skills and abilities that are especially prone to be supported through educational games.

Intrinsic Motivation

Malone and Lepper (1987) offer a detailed argument on just how important intrinsic motivation is to the designer of educational (computer) games. They identify four individual factors as well as three interpersonal factors that are elementary to providing and maintaining intrinsic motivation (Table 1).

As stated by Connolly et al. (2008), it is safe to say that the effect of (computer) games-based learning has been analyzed from a variety of both negative (e.g., aggression, violence or gender stereotyping) as well as positive (e.g., skills development, engagement, learning or motivation) perspectives. In all these, as two successive comparative studies by Connolly et al. (2007a, b) have shown, *curiosity*, *challenge* and *cooperation* consistently emerged as the most important motivations for playing computer games.

Fundamental Principles of Good Games

Besides aiming at important aspects of intrinsic motivation identified in the previous section the game should aim to include as many as possible of the fundamental principles of good games. There is an extensive body of literature that tries to identify those principles; Gee (2003, 2004, 2005) identified the following (Table 2).

These principles are:

- *Identity*: Through fictional identities, a game stimulates the player to embrace a new role and to take on the corresponding responsibilities. Adapting this new role requires learning new domain knowledge.
- *Interaction*: Players experience responses/feedback to their actions.
- *Customization*: Customizing a game to the specific interests of a group elicits the group's interest and provide stimulating challenges.
- *Production*: Decisions of the players directly impact events in the game.
- Risk Taking: Since the game provides a standalone environment in a virtual world, actions in the game rarely have consequences in the real world, inviting the player to experiment and to take risks.
- *Challenge and Consolidation*: Through repetition, the player can master skills and advance through increasingly challenging stages.
- *Pleasantly frustrating*: Good computer games have realistically attainable goals that are, while achievable, at the outer edge of the players *regime of competence*.
- *Well-ordered problems*: Offering an underlying structure to presented challenges motivates the player to consider the problems on an abstract level. This allows to draw on previous experiences to solve future problems.
- *System thinking*: Good games encourage or even require players to think about the effect their decisions have on the course of the game. As a result a player considers abstract relationships instead of isolated events.
- *Agency*: Giving the player a sense of ownership over their decisions.

When creating a serious game, the designer should try to include and address as many of the above as possible. In the next section we discuss key skills that have been shown to be supported by GBL. It is unlikely that any one game will target all of these skills equally or even at the same time. The principles listed above should be adopted, but which principles should receive the largest attention will be determined by the targeted skills.

Key Skills Supported by Games-Based Learning

A (non-exhaustive) list of key skills that have been shown to be promoted by serious games has been published by Hildmann and Hirsch

Computer Games in Education, Table 1 The individual and interpersonal factors considered to be the main factors provide and maintain intrinsic motivation (Malone and Lepper 1987)

Individual factors	Interpersonal factors
Challenge	Cooperation
Fantasy	Competition
Curiosity	Recognition
Control	

Computer Games in Education, Table 2 Fundamental principles of good games, cf. Gee (2003, 2004, 2005)

Identity	Challenge & Consolidation
Interaction	Pleasantly frustrating
Customization	Well-ordered problems
Production	System thinking
Risk taking	Agency

(2008). For a detailed discourse on these the reader is referred to Healy (2006) (Table 3).

Considerations, Shortcomings, and Disadvantages

Computer games are more and more considered as tools in the education sector (Pee 2011). This interest notwithstanding, there are many negative aspects of games acknowledged in the literature such as e.g., the increase of aggressive behavior (Uhlmann and Swanson 2004) or the decrease in physical exercise (Liliana Escobar-Chaves et al. 2010).

Among these negative aspects is also the proven fact that computer games can be extremely addictive (which should be unsurprising since gambling, known to be highly addictive, is often embodied by a game). The fact that games can become an alternate reality to which the player can escape from real world problems has been widely discussed, and while this surely has large potential for negative consequences, it is also a property that motivates the use of games as educational tools: problems that real life scenarios and approaches inherently face can often be completely ignored in games.

Lack of Supporting Evidence

While we have motivated the benefits of using computer games in the educational sector, the GBL approach is far from being accepted by all practitioners in the field. There are plenty of reasons to caution against hailing the use of computer games as a silver bullet for all educational challenges. For example, an investigation conducted 25 years ago by Randel et al. (1992) found that only ≈50% of the considered studies showed any significant difference between using games and using conventional instructions. The field has certainly evolved since the 1990's and market analysts consider games-based learning to be one of the fastest growing division in the eLearning market (cf. Connolly et al. 2008), but commercial success does *not* imply the validity of an approach. As Gura (2005) cautions: *"[e]ducation is a highly politicized field, [. . .] littered with obstacles to reform and populated by powerful individuals with their own pet theories"*. The fact that there is a market for the idea does not imply that the idea works; it merely suggests that it is selling well. It is not uncommon that the performances and benefits claimed by the marketing departments of major game producers are met with considerable skepticism by some experts in the field (cf. Fuyuno 2007).

There is a shortage of solid evidence for the validity of using computer games for teaching, training and instruction Connolly et al. (2007b). Furthermore, a fair number of known shortcomings are in need of receiving more attention from the community. Examples of such open challenges are the distinct lack of frameworks or guidelines. GBL continues to attract attention by funding bodies and, to a lesser degree, acceptance as a mainstream approach for learning and teaching, and the focus should be on guidelines and frameworks to support other advances in the field.

However, it is also the case that games *for play* are often perceived differently from games *for serious purposes*. When this distinction is made by the player it can have a significant impact on the willingness to engage in a game and – as a result – on the benefits gained from playing that game. If knowing whether a game is meant to be serving a serious purpose affects the performance of the game, then cunning game design and the framing of learning activities becomes a significant factor. This makes objective evaluation even more difficult and once again highlights the importance of applying best practices from the fields of psychology and pedagogics when engaging in the development of serious games.

Computer Games in Education, Table 3 A summary of the key skills that can be promoted through serious games (cf. Hildmann and Hirsch 2008), for a full discussion the reader is referred to Healy (2006)

Problem solving	Communication
Analytical thinking	Discovery
Team working	Negotiating
Social and cultural	Logical thinking
Critical thinking	Visualization

Lack of Interdisciplinary Communication

The field of games-based learning and serious games is commonly dominated by experts from the computer games industry and commercially driven by companies. In Hildmann and Hildmann (2009), the authors emphasize the gap between approaches to teaching and learning offered through GBL and established models for human learning (from cognitive or behavioral psychology) or validated practices used by teachers in classrooms. In light of the large amount of funding recently offered for the development of new learning approaches, there is the danger of overlooking basic needs and requirements. This problem is well documented in the literature: Powell (2003) states that *"some education experts argue that the scientists who are now developing an interest in the subject are ignoring prior research"*, while Gura (2005) goes so far as to claim that *"[u]ntil now, science and educational research have not mixed well"*. While more recent publications increasingly acknowledge the need to integrate alternative approaches instead of imposing them on the field (e.g., McGonigal (2012): *"The future will belong to those who can understand, design and play games"*), there is still the issue of verification and comparison of the usefulness of contributions. While the short-term gains from heeding the advice of pedagogues, psychologists and practitioners in the training sector may be reduced, the long-term benefit (both financially as well as with regard to the actual performance of the created products) can only increase. Therefore, computer scientists and game designers have to start listening more to the practitioners. At the same time, the education sector is undergoing fundamental changes and teachers in a classroom have to accept that old teaching paradigms might have become outdated or may be falling behind what is technically possible. Even without challenging any of the established theories about how children learn, the world in which today's children grow up is vastly different from the world into which senior educationalists were born. All sides need to acknowledge that there are contributions from other fields, and that only by working together and fostering interdisciplinary communication can GBL achieve its full potential.

Cross-References

- ▶ Computer Games and the Evolution of Digital Rights
- ▶ Gamification
- ▶ Gamification and Serious Games
- ▶ Serious Online Games for Engaged Learning Through Flow
- ▶ Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

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Computer Generated

► Postproduction in Game Cinematics

Computer Go

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Synonyms

Computer Baduk; Computer Weiqi

Definition

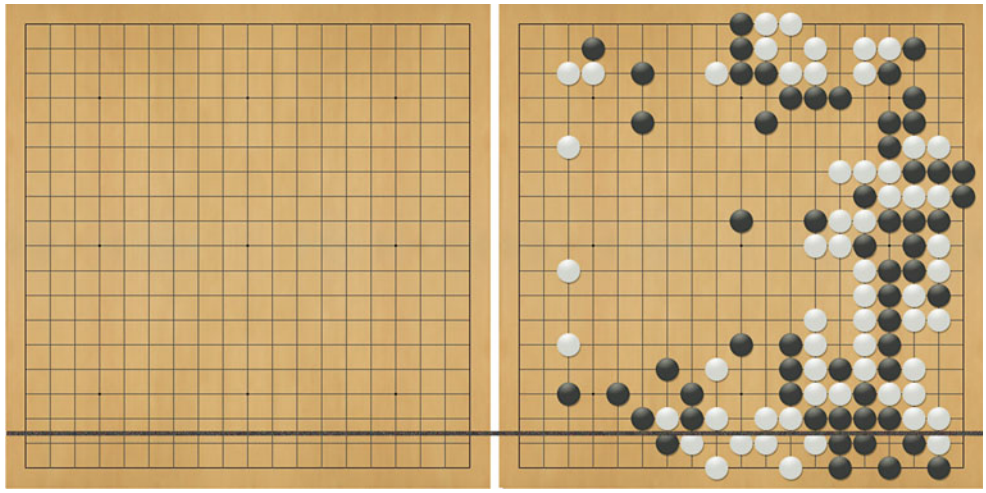
Computer Go was an interesting target in AI domain because Go was exceptionally difficult for computers among popular two-player zero-sum games.

Overview

As widely known, computers are now superior to human beings in most of the popular two-player zero-sum perfect information games including checkers, chess, shogi, and *Go*. The minimax search-based approach is known to be effective for most games in this category. Since Go is also one of such games, intuitively minimax search should also work for Go. However, despite the simple rules which had changed only slightly in these 2,000 years, Go is arguably the last two-player zero-sum game in which human beings are still superior to computers.

The solution to the difficulty of Go was a combination of random sampling and search. The resulting algorithm, Monte Carlo tree search (MCTS), was not only a major breakthrough for computer Go but also an important invention for many other domains related to AI. The strength of computer Go had rapidly improved since the invention of MCTS.

This entry consists of introduction to the game of Go and computer Go topics before and after the invention of MCTS.

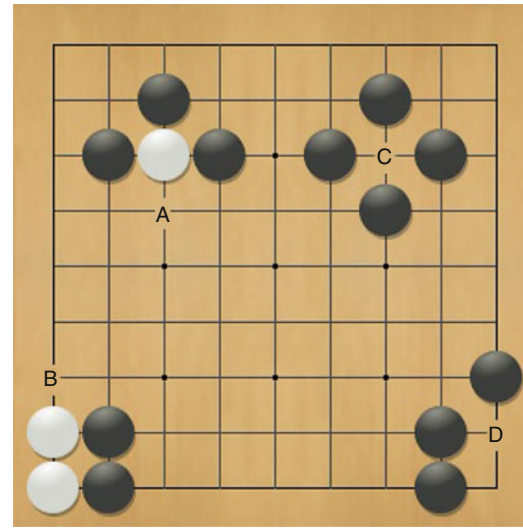


Computer Go, Fig. 1 *Left*, An empty 19*19 board. *Right*, middle game position taken from one of the most famous games in Go history

Game of Go

History of the Game

The game of Go originated in China and had been played for more than 2,000 years. It is one of the most popular two-player board games. The game is called *Go* or *Igo* in Japan, *Baduk* in Korea, and *Weiqi* in China. Because the Japanese Go association took main part in spreading Go to the world, *Go* became the most popular word for the game. The word *Go* will be used for this entry. Most of the players reside in East Asia but in the last century it got more popular in the rest of the world. The population of Go players is thought to be approximately 40 million. There are professional organizations in East Asian countries, and several hundreds of professional players belong to these organizations.



Computer Go, Fig. 2 Capturing and illegal move

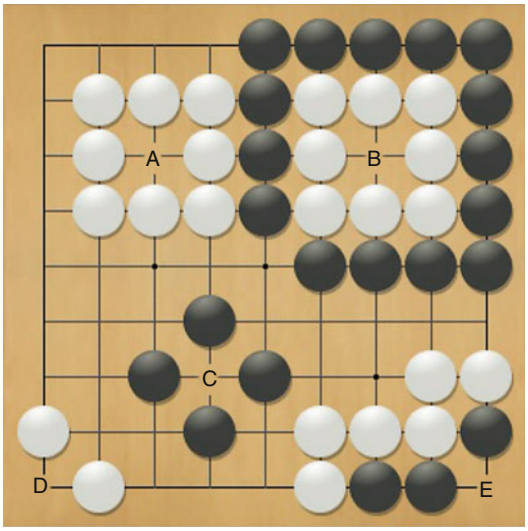
Rules of Go

Equipment

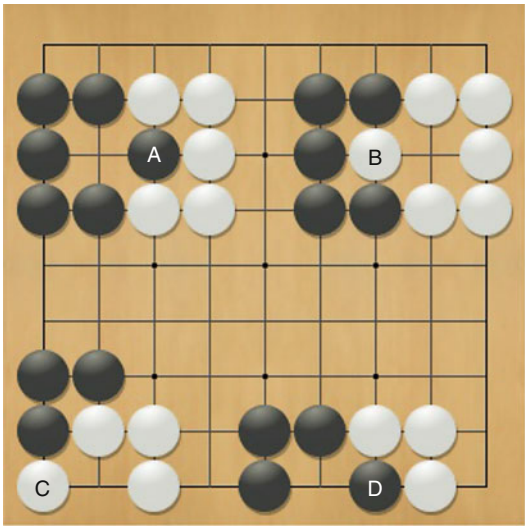
Go is played on a board with a grid. Players alternately place one stone at a time on an empty intersection of the grid. The first player uses black stones and the second player uses white stones. The aim of the game is to occupy as much *territory* as possible. A 19 × 19 grid is used in official rules. For beginners and short-time games, 9 × 9 or 13 × 13 grids are also used (the rule is independent of the size of the grid and it can be played on arbitrary-sized board) (See Figs. 1 and 2).

Capturing

Once placed, stones never move on the board. Stones get connected in four directions, vertically or horizontally (do not connect diagonally).



Computer Go, Fig. 3 Suicide moves, eyes



Computer Go, Fig. 4 Examples of Ko

Connected stones form a *block*, and if a block gets completely surrounded by opponent's stones, the block will be *captured* and removed from the board. Capturing opponent stones is often advantageous because it results in greater chances to occupy more territory.

Empty intersections adjacent to a block are called *liberties*. If a block has only one remaining liberty, the block is in *atari*. Capturing occurs if an opponent stone occupies the last remaining liberty of a block. Examples of capturing are shown in Fig. 2. If black plays on A or B, the white blocks are captured and removed, as shown on the right side.

Suicide and Eye

It is prohibited to place a stone if the stone (or the block which contains the newly placed stone) has no liberties. In other words, suicidal move is prohibited. For example, white is not allowed to play at C in Fig. 2.

However, black is allowed to play at B in Fig. 3 because it can capture the surrounding white block and make liberties for the black stone at B. In Fig. 3, A, D, and E are all illegal moves for black. B and C are illegal moves for white.

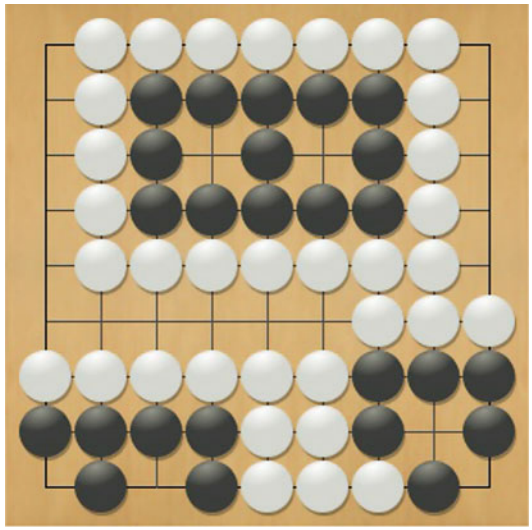
A single empty intersection surrounded by the stones of the same color is called an *eye* (in Fig. 3, A and D are white's eyes and C is a black's eye). Making eyes is important for the game (cf. section "Life and Death").

There is a variation of rules which allows suicide of more than one stones (e.g., New Zealand rules). It gives some effects to theoretical analysis but will not be described in details in this entry because it is rarely used.

Ko and Repetition

Similar to other board games, Go has a rule about avoiding repetitions. The simplest and most popular case of repetition occurs by capturing an opponent stone resulting in a stone with only one liberty. The example is shown in Fig. 4. Black captures a white stone by playing on A and then white can capture back the black stone by playing on B. The stones marked C and D are also in Ko. To avoid infinite recapturing, a player must play another move, called *Ko threat*, before capturing back. Ko adds more complexity in the game (both in practice and theory) and often makes it more interesting.

There are several variations in repetition avoiding rules. Super Ko rule prohibits global repetition (which of course includes simple Ko) (*Super Ko* means the global repetition.) For human beings, accurate detection of Super Ko during real games is difficult, and it is excluded



Computer Go, Fig. 5 Safe (living) blocks

from some of the official rules for human tournament (e.g., Japanese Go association official rules).

However, computer Go tournaments typically use Super Ko rule because it is not a problem for computers. There are two types of Super Ko rule. Situational Super Ko distinguishes the same board position if the next player is different and positional Super Ko does not.

Life and Death

If a player owns a group of stones (consisting of one or more blocks) which has two or more *eyes*, the group will never be captured by the opponent, unless the owner intentionally fills one of his own eyes (filling own eye is almost always a terrible move).

Groups safe from capturing are *alive*. If a group cannot avoid capturing, it is *dead*. As the game ends, all stones on the board will be either *alive* or *dead*. The black blocks in Fig. 5 are all alive. Life and death is not a part of the rule, but it is a natural consequence of the rules and the concept is crucial for the game.

End of Game and Scoring

For the game of Go, pass is always a legal move. Players can pass if there is no other beneficial move remaining. The game ends if two consecutive passes are played. If the game had ended by passes, the winner is decided by the score. (Of course, players are allowed to resign at any moment. The opponent will be the winner.)

There are two rules for scoring, *area scoring* and *territory scoring*. Area scoring counts the sum of:

- The number of empty points only one player's stones surround
- The number of stones of each player
- *Komi* points to compensate the advantage of the first player

Territory scoring counts the sum of:

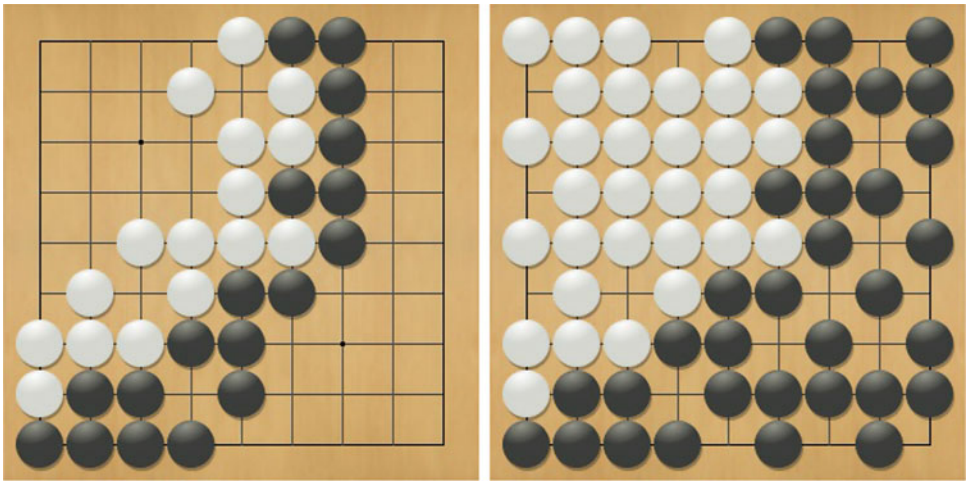
- The number of empty points only one player's stones surround
- Minus the number of stones captured by the opponent
- *Komi* points to compensate the advantage of the first player

The outcome is similar for both rules and the difference rarely affects human players. However, how to correctly handle territory scoring is an interesting topic for computer Go. Area scoring is more computer friendly and used in most compute Go tournament.

Strength of Human Players

Strength of the players is measured by *kyu* and *dan*. Human players are given a 25-kyu rank after learning rules. As players improve their strength, the number decreases until it reaches 1 kyu. Players of different ranks can play even games using handicap stones because having more stones in the opening is more advantageous. The difference between the ranks is used as the number of handicap stones (e.g., a 5-kyu player and a 1-kyu player play with four handicap stones).

Shodan (which means first dan) is given to players who are 1-stone stronger than 1 kyu, and then the number increases for stronger players. It normally requires more than 1 year of training to



Computer Go, Fig. 6 9 × 9 board endgame examples

Computer Go, Table 1 Computer strength for two-player zero-sum games without Monte-Carlo Tree Search (as of 2015)

Game	Strength
Checkers	Perfect play is possible
Othello	Stronger than human champion
Chess	Stronger than human champion
Shogi	Approximately as strong as human champion
Go 9 × 9	Approximately 3 kyu (based on authors' guess)
Go 19 × 19	Approximately 3 kyu

reach shodan. The strongest amateur players are rated approximately 9 dan. Professional players also use the same word *dan*, but the difference is not measured by the number of handicap stones (Fig. 6).

Computer Go Difficulty

Theoretically, minimax search can find the optimal move for two-player zero-sum perfect information games. For most popular games in this category, minimax search combined with alpha-beta pruning (e.g., alpha-beta search) actually succeeded in making programs which is at least as strong as human champion (Fig. 1). Go is the only exception in this category of games (Table 1).

Computer Go, Table 2 Search space size of two-player games

Game	Search space
Checkers	10^{20}
Othello	10^{28}
Chess	10^{45}
Shogi	10^{70}
Go (19 × 19)	10^{172}
Go (9 × 9)	10^{38}

Difficulty: Search Space Size

One of the difficulties of the game of Go is the enormous search space size. The search spaces of popular two-player zero-sum games are listed in Table 2 (numbers are from Schaeffer et al. 2014). The game of Go has the greatest search space size. Checkers was solved by exhaustive search in 2007. Go search space is far beyond the limit of current (and at least near future) computational power.

It is empirically known that computers tend to be stronger for smaller games if the rules are similar. However, there was a small difference in the strength of 9 × 9 Go and 19 × 19 Go for non-MCTS programs. This fact indicates that the search space size is not the only reason for the difficulty of Go.

Difficulty: Evaluation Function

Among the games shown in Table 2, only checkers is solved by exhaustively searching the game states. For the rest of the games, the search space is too enormous. Therefore, minimax search prunes unpromising branches based on evaluation functions. Fast and accurate evaluation functions for the games were made using a combination of handcrafted codes and machine learning techniques.

Despite the simple rules, Go was the only exception. It is widely believed that making evaluation function for Go is difficult compared to other two-player games. There are many explanations for the difficulty. Unlike chess, there is no clue such as the value of the pieces because all stones are identical. Unlike Othello, focusing on important portions of the board (e.g., corner points or edges) didn't work. Because it is a territory-enclosing game, it seems like it is possible to predict the final territory, but it is only possible in the late endgames. Seeking for local goals such as capturing opponent stones often does not help in finding globally good moves.

The best evaluation functions developed for Go (as of 2014) was either too slow or inaccurate. Minimax search does not work without an evaluation function. A survey paper published in 2002 (Müller Jan. 2002) listed research challenges in computer Go. The first challenge in the list seems very trivial: "Develop a Go program that can automatically take advantage of greater processing power." It emphasizes the fact that Go needed a new approach.

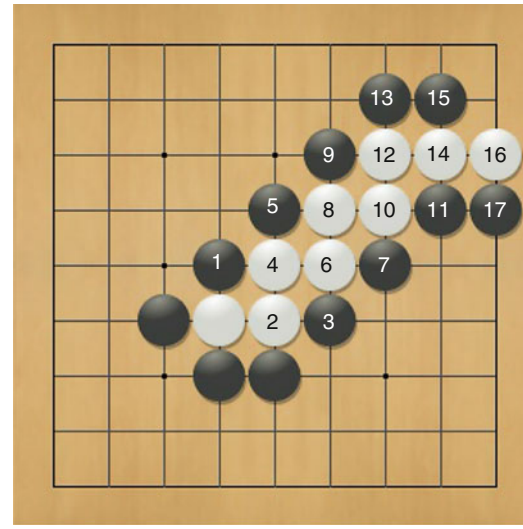
Before Monte Carlo Tree Search

Local Tactical Problems

The Go board is large enough to have multiple local tactical fights. Although there is no guarantee that locally good moves are globally good moves, blunders in local fights are often fatal.

Ladders

Ladder is a simple but important technique in Go. Capturing a block after a sequence of *ataris* is called a ladder, which normally results in a zigzag shape (Fig. 7). Many Go programs use ladder search as one of the tactical components.



Computer Go, Fig. 7 Ladder example

Semeai

Another tactical problem is the *capturing race or semeai*, which is a variation of capturing problems. Capturing race occurs when two groups of different colors are adjacent in an encircled space and can live only by capturing the other group. Normal algorithms for solving two-player games such as minimax search (alpha-beta search) and proof number search could be used to solve the problem.

Life and Death (Tsumego)

One of the most important local tactical fights is the *life-and-death* problems, also called *Tsumego*. (In formal definition, Tsumego means life-and-death problems with only one correct move, but it is often used as the same meaning.)

Killing (and capturing) a large group of stones is advantageous in general. Therefore, in real games, it is crucial to correctly analyze life and death of stones. Alpha-beta search-based solver and df-pn (depth-first proof number) search-based solver are both known to be effective.

If the problem is enclosed in a small region, these solvers are much faster than human players. However, open-boundary Tsumego is still difficult for computers.

Theoretical and Practical Analysis

Solving Go on Small Boards

The smallest size of the board which makes the Go interesting for human players is probably 5×5. Go on 5×5, 5×6, and 4×7 is solved by search (van der Werf 2015).

Computational Complexity

Go using Japanese rules is proved to be EXPTIME-complete (Robson et al. 1983). The proofs with Chinese rules, the class is only proved to be somewhere between PSPACE-hard and EXPSPACE.

Endgame Theory

Since Go is a territory-occupying game, the value of each move can be described as the amount of territory it will occupy. Combinatorial game theory (CGT) (Berlekamp and Wolfe 1994) shows how to systematically analyze the values of moves as a sequence of numerical values and how to choose the optimal move after these analyses. CGT solves difficult artificial positions better than human professionals, but there is no program which actually uses it in the play.

One-Ply Monte Carlo Go

Because it was difficult to make good evaluation function for Go, there was a different approach called one-ply Monte Carlo Go. (It was originally called Monte Carlo Go, but to distinguish from Monte Carlo tree search, the term one-ply Monte Carlo Go will be used throughout this entry.)

Because the number of legal moves decreases, it is possible for randomized players to end the game naturally according to the rules. If both players randomly choose one of the legal moves, the game will continue for a long time because filling own eyes results in repeatedly capturing large blocks. However, given a simple rule to avoid filling its own eyes, the game will end in a reasonably short time (average number of moves will be approximately the same as the number of the intersections of the board). In this way it is possible to evaluate the given positions by letting random players play both sides and count the territory. The random play sequences until the endgame is called *playout*.

The basic idea is illustrated in Fig. 8. A given board position will be evaluated by the average score of the playouts performed from the position. In the figure, black had won 2 out of 3 playouts. Therefore, the position might be promising for black.

This is an extremely simple idea. All legal moves are evaluated by playouts, and the move with the highest winning rate will be chosen (the left most branch in Fig. 9). Unsurprisingly, one-ply Monte Carlo Go is weak because of a fundamental weakness.

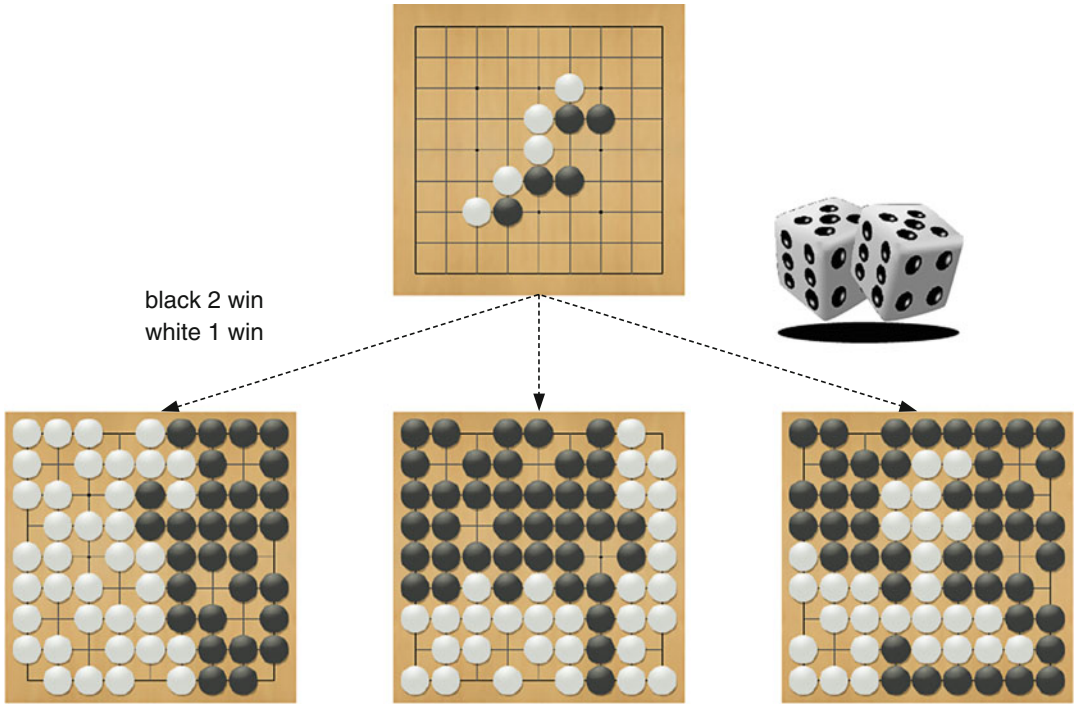
Assume that the playout is purely random except avoiding eye-filling moves. If there is a threatening move with only one correct reply, the opponent will likely to choose the wrong reply in the playouts. Therefore, such a move will be evaluated highly. The one-ply Monte Carlo Go program likes to play direct atari moves which are, in most cases, useless moves. In short, it tends to choose moves which expect opponents to make blunders.

The chance of choosing nonoptimal moves will not be zero even given infinite computational time. The limit of the strength is analyzed when using simple playouts. The winning rate against GNU Go on 9×9 board was approximately 10 %, and it was also extremely weak on 19×19 boards.

The first known work was described in an unpublished report written by Brügmann in 1993 (Brügmann 1993). There was more sophisticated approach based on one-ply Monte Carlo Go. They had comparable strengths with other approaches, but it was clearly not the most successful approach for Go. However this idea is important because it triggered the invention of the Monte Carlo tree search algorithm.

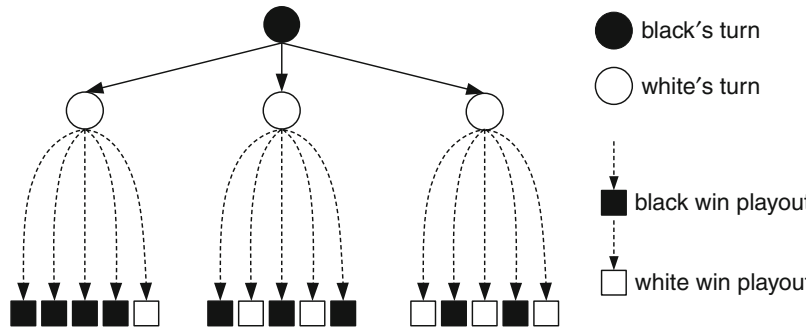
Monte Carlo Tree Search and Go Programs

As described above, one-ply Monte Carlo Go introduced a new way of evaluating the board position which does not require an evaluation



Computer Go, Fig. 8 A 9 × 9 board evaluation by playout

Computer Go, Fig. 9 Simplest one-ply Monte Carlo Go



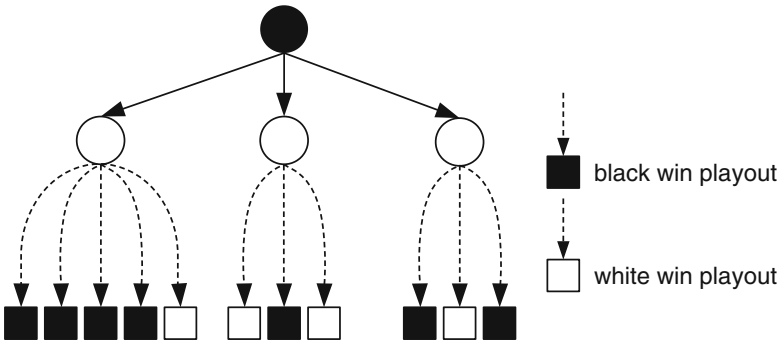
function. But there was also a fundamental weakness. The breakthrough came in the year 2006.

Brief History of MCTS Invention

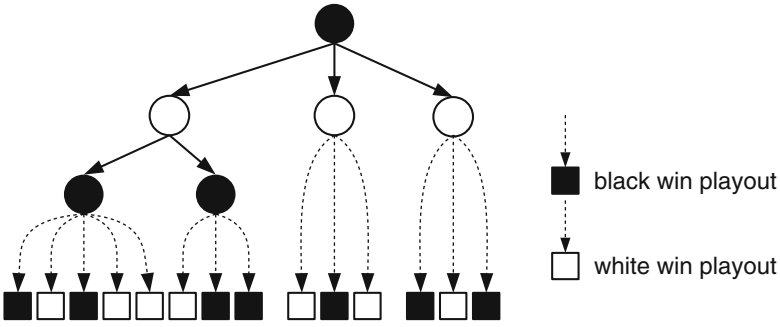
Go program Crazy Stone, developed by a French researcher Rémi Coulom, is the winner of the 9 × 9 Go division of the 11th Computer Olympiad taken place at Turin in 2006. The algorithm used in Crazy Stone was published at the same time in Computers and Games Conference which was one of the joint events with the Olympiad (Coulom et al. 2006). It is widely regarded that the algorithm developed for Crazy Stone by Coulom is the first MCTS algorithm.

Based on the success of Crazy Stone, Kocsis and Csaba Szepesvári submitted the paper about Upper Confidence applied to Trees (UCT) algorithm to ECML 2006 Conference (Kocsis and Szepesvári 2006). UCT had the proof of convergence to the optimal solution which Crazy Stone's first approach did not have (explained in section "UCT Algorithm").

Computer Go,
Fig. 10 Enough playouts on promising branches



Computer Go,
Fig. 11 Expand promising nodes



At first, it seemed MCTS works only for small boards. However, soon after the UCT paper was published, a Go program named MoGo became the first Go program to achieve a shodan on 19 × 19 board (Gelly et al. 2006) (on an Internet Go server, KGS (KGS Go Server 2015)) and became famous among Go players.

Basic Framework of MCTS

The differences between one-ply Monte Carlo Go and MCTS seem simple. First, more playouts will be performed from more promising branches (Fig. 10). Then if the number of playouts on a leaf node exceeds a threshold, the leaf will be expanded (Fig. 11). With these modifications, the tree will grow in an unbalanced manner growing toward the promising parts of the tree. It covers the weakness of the one-ply Monte Carlo Go programs and significantly improved the strength.

However, at this point, the definition of promising branch is not clear. The key point of the algorithm is the selection of promising branches which is explained in the following sections.

Theoretical Background: Multi-armed Bandit

The basic approach was surprisingly simple. However, promising branch has to be decided appropriately. Possibly the simplest approach is to select the branch with the highest mean reward. But it is obviously a bad idea, because if the first playout of the (unknown) optimal branch had lost, it will never be selected again. Therefore, the selection method has to give an advantage to branches with small number playouts. More formerly saying, for MCTS to be successful, branches with large confidence interval must be given a positive bias. Theories of the multi-armed bandit (MAB) problem gave a solution. MAB is an old problem which is studied from 1930s.

The problem settings are as follows. You have a certain number of coins and there is a slot machine which has a number of arms. Each arm returns a reward based on an unknown distribution. The goal is to find a strategy which minimizes the expected value of cumulative *regret*. Cumulative regret of a strategy is the difference between the sum of the expected reward of the strategy and the sum of the ideal optimal reward which could be obtained by pulling the optimal arm every time. (There are many different formulations of MAB but this entry focuses on the settings which is related to MCTS and Go.)

Intuitively, part of the coins must be used to explore the arm, and the majority of the coins should be spent on the optimal arm. This is called the exploration-exploitation dilemma.

Analysis of the theoretically optimal solution is already given in 1985 by Lai and Robbins (Lai and Robbins 1985), but their algorithm was complex and time consuming. Auer et al. proposed a tractable and also optimal (with constant factor difference) strategy based on upper confidence bound (UCB) (Auer et al. 2002). They proposed several strategies but here we only introduce UCB1. Algorithm UCB1 chooses the arm with the highest UCB1 value which is defined as

$$\mathrm{UCB1} = \overline{X}_i + C\sqrt{\frac{\ln t}{s_i}} \qquad (1)$$

where $\overline{X}_i$ is the mean reward of i-th arm, s_i is the number of coins spent for the i-th machine, t is the total number of coins spent so far, and C is a constant called the *exploration constant* which is defined based on the range of the reward. For the proof described in Auer et al. (2002) to hold, C should be $\sqrt{2}$ if the range of the reward is [0, 1]. However, it is also proposed that C should be adjusted for the target problems to achieve better performance.

The first term is the *mean term* and second term is the *bias term*. While arms with higher mean tend to be chosen, the bias term gives an advantage to arms with small number of coins.

MAB	—	One-ply MC Go
arm	—	move
coin	—	playout
nu. coins	—	thinking time
minimize regret	?	optimal move

Computer Go, Fig. 12 Relation between MAB and one-ply Monte Carlo Go

There is a close relation with MAB and one-ply Monte Carlo Go (Fig. 12). Each arm is a move, one coin is one playout, and the number of coins stands for the amount of the thinking time. The goal is slightly different, but as explained in the next section, UCB1 works well if combined with tree search.

UCT Algorithm

UCT is a tree search algorithm which uses UCB1 for branch selection. UCT does the following procedure repeatedly until a given time limit is reached or a given number of playouts are performed:

1. Follow the branch with the highest UCB1 value until reaching the leaf node.
2. If the number of playouts at the leaf exceeds a given threshold, expand the node.
3. Do one playout.
4. Update the values of the nodes on the path.

UCT is a generic algorithm which works for various problems, and it also has a proof of converging to the optimal solution if the range of the playout reward is in [0, 1]. However, in the same way, as the constant in UCB1, *exploration constant C* should be adjusted for UCT also (e.g., to make Go programs stronger).

Reward Definition and Playing Style

Crazy Stone attracted the attention of Go programmers not only with the strength but also with the unique playing style. It won many games by the smallest possible margin by intentionally (it looked like so) playing safe-win moves.

Play aggressively when losing; play safely when winning. It was a very difficult task for minimax search-based programs. But MCTS-based Go programs naturally acquire this ability. It is based on the definition of playout rewards. Since Go is a score-based game, it is possible to use the score itself as the reward. However, if the reward is two valued (e.g., 1 for win and 0 for loss), MCTS tries to maximize the winning probability, not the score difference. The early version of Crazy Stone was using the score as the reward, and the winning rate against GNU Go was in 30–40 % range. After the reward was changed to 0, 1, it jumped up to higher than 60 %.

Why MCTS Works for Go (Or Weakness of MCTS)

MCTS has a generic framework and it drastically improved Go program strength. But, of course, it is not an all mighty algorithm. Theoretical and practical analysis revealed the weakness of MCTS if the tree has a *deceptive structure* or *trap*.

A *trap* is a tree where a small number of branches have significantly better (or worse) values than other branches. If a long sequence *trap* is in the tree, it is highly unlikely for MCTS to find the correct solution. In Go the situation typically occurs in a *ladder* where only one move is the correct move and all others are blunders. Early MCTS-based Go programs did actually miss long ladders in real games.

A Go proverb says, "if you don't know ladders, don't play Go." It is impossible to make a strong Go program without correctly recognizing ladders. Recent Go programs handle ladders by playouts. As explained later in section "Playout Enhancements," playouts used in recent Go programs are far from random. The ladder sequences in real games are simple and playouts can solve them. From the viewpoint of the tree search algorithm, the *trap* is removed by playouts.

MCTS is a combination of tree search and playout. Playout can read simple deep sequences. Tree search can select the best branch from various options. If the combination is effective, MCTS works well. However, there are often needs for reading long sequences of moves in tactical situations (capturing or life and death is typical). It is difficult to make playouts correctly read tactical sequence. This is widely regarded as the remaining weakness of MCTS-based Go programs.

C

Enhancements for MCTS-Based Go Programs

RAVE and AMAF

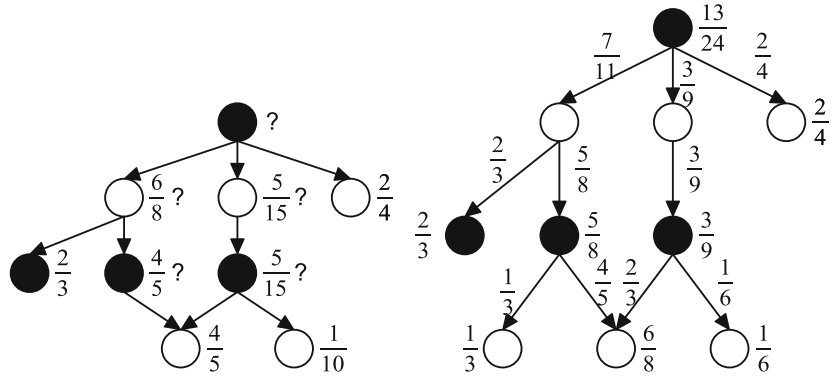
UCT has a proof of convergence and works fairly well, but state-of-the art Go programs (as of 2015) are not relying on UCT. Practitioners ignored the theory and replaced the bias term with other terms using Go knowledge. Rapid Action Value Estimation (RAVE) is one of the most popular techniques used in Go (Gelly et al. 2007).

Occupying a point is often crucial in Go regardless of the order of moves. A heuristic technique called All Moves As First (AMAF) heuristic is invented based on this observation. Instead of forgetting the sequence in playouts, AMAF updates the values of all moves that appeared in playout sequences. It is inaccurate but the update speed is improved by a large margin. In RAVE, branches with small number of playouts use AMAF-based values, and as the playouts increases, it is gradually replaced by true values of playouts.

Playout Enhancements

Improving playout quality is the most important and subtle part of MCTS-based Go programs. Both handcrafted approach and machine learning approach succeed (as of 2014).

MoGo had used handcrafted playouts, and it is said that program Zen (one of the strongest programs in 2014) also uses at least partly handcrafted approach. Many other programs use different approach. Pattern-based features are defined by programmers and the weights are adjusted by machine learning. Typically, game records played by strong players are used as training data, and the objective function will be the



Computer Go, Fig. 13 Transpositions and UCT

matching rate with the expert moves. In both approaches, the playouts will choose more "reasonable" moves which makes it possible to solve simple tactical situations including ladders. How to make good playout is still not clear because playout and tree search are correlated in a complex manner and theoretical analysis is difficult.

Progressive Widening

To find good moves in game playing, search must focus on promising part of the tree. In MCTS, *progressive widening* method is popularly used for pruning unpromising part. If the number of playout at a node is small, only few branches will be selected as the target of search. As the number of playouts increases, more branches are added.

Parallelization

Using shared memory parallel, MCTS is common for strong Go programs. Normal implementation based on lock mechanism achieves speedup on multi-core machines. It is also known that the performance could be improved by using *lockless hash* technique.

For distributed memory environment, root parallel approach is used by several strong programs. Each compute node independently searches with different random seeds, and a small part of the tree is shared among the compute nodes (e.g., tree nodes with depth 1–3 are shared). It is known to scale well for up to several dozens of computers.

Transpositions and MCTS

Game tree of Go is actually not tree but a directed cyclic graph. *Transpositions* often occur when different sequence of moves results in the same board position. As shown in the left of Fig. 13, it is not trivial to decide the win rate of nodes for DAGs. Efficient handling of transpositions in MCTS is still an interesting open problem (Fig. 13).

Go programs uses mainly two ways. One is to ignore transpositions and use trees. This is wasting computational time, but it is possible to make strong enough programs based on trees. The other is to record the values separately for nodes and branches. UCT is proved to converge to the optimal solution if the values stored in nodes are used for *mean term* and values of the branches are used for the *bias term*, as shown in the right of Fig. 13.

Implementation Techniques

Here is a list of common components and techniques for modern Go programs:

- Fast data structures for Go board, including block and pattern information.
- Fast pattern matcher including simple 3×3 matcher and heuristic features needed in both machine learning phase and playing phase.
- Machine learning methods.
- Zobrist hashing for fast hash value calculation.

- Game database used as training data for machine learning and opening book construction.
- Time control for playing games in tournament.
- *Pondering* (thinking while the opponent is thinking) and tree (or hash table) reuse.
- Dynamic *komi*. Especially important for handicapped games. Adjust virtual *komi* to avoid playing too safe (too aggressive) moves.
- Using the results of tactical searches such as capture search or life-and-death search.
- Opening book.

Concluding Remarks

Current Computer Go Strength

N. Wedd maintains a Web page titled "Human-Computer Go Challenges" (Wedd 2015). After the invention of MCTS, strength of Go programs improved rapidly. From 2012 to 2014, strongest Go programs (Zen and Crazy Stone) have played several 4-stone handicapped games against professional players including former champions (4-stone handicap means approximately 4-dan difference.) The results include similar number of wins and losses.

Discussion

Before the invention of MCTS, Go was regarded as a grand challenge of game AI research because of the difficulty. The difficulty of Go led to the invention of an epoch-making algorithm, Monte Carlo tree search. Many MCTS-related researches exist both in theory and application and in game and nongame domains. Still, Go is the most intensively studied target for MCTS.

There are many studies about search algorithm and machine learning, which is combined with many implementation techniques. Many researchers are working how to exploit increasing computational power of recent computers. Recently, at the end of year 2014, the first success of deep learning approach for Go was reported. Deep learning could be the candidate for the future breakthrough. It is still in early research phase, but the results seem promising.

Computer Go is improving rapidly and it is difficult to predict even in the near future. At least for some more years, Go is likely to remain as one of the most interesting challenges in game AI.

Cross-References

▶ Monte-Carlo Tree Search

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Computer Graphics

▶ Planetary Generation in Games

Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being

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Synonyms

Biofeedback; Gamification; Gesture motion; Healthcare; Rehabilitation; SoundScapes; User interaction; Video games

Definitions

Biofeedback	A sensing and response system that sources physiologic human data (typically using sensors on- or off-body) mapped to selectable content (typically digital) as feedback to self-inform participants of their input consciously, subconsciously, or subliminally. Often used in treatments to teach patients to modify specific physiologic functions.
Gamification	Application of game elements within a typically nongame context. Contextually, in this case [re]habilitation, healthcare, and interactive performance art, targeting participant motivation, immersion/engagement, and playfully rewarding positive experiences offering inclusive well-being. (Regaining skills, abilities, or knowledge that may have been lost or compromised as well as helping disabled people attain, keep, or improve skills and functioning for daily living – in line with the Convention on the Rights of Persons with Disabilities (CRPD).).
Gesture Motion	Movement of the limb, torso, or whole body within a sensing space.
SoundScapes	Contextually specific referring to an author-conceived bespoke accessible, inclusive, and interactive multimedia environment targeting, through adaptive personalization, creative expression, and playful interactions alongside user experiences of enjoyment, fun, and entertainment. Utilized as an alternative intervention concept in healthcare and rehabilitation to improve participation in treatment programs. The concept is informed from the author's audiovisual art.
Video Games	Computer graphics and sound elements comprising a "virtual environment" within which players interact (via an input device) with typically animated objects displayed on a monitoring device for the sake of entertainment.

Introduction

As Tolstoy stated in "What is Art?" (Tolstoy 1995 [1897]) – *Art is a human activity consisting in this, that one man [or woman] consciously by means of certain external signs, hands on to others feelings he has lived through, and that other are infected by these feelings and also experience them*. In the text he states how *art is a form of consciousness*, framing in so doing the

essential role of art as a vehicle of communication and empathy.

On a more recent note than Tolstoy, Grau (2003) posited: . . .*ultimately, it is the intellectual vision, transposed into the work step by step with technology as its reference, that remains the core of a virtual work of art*.

This article introduces a body of work where the catalyst is creative expression and playful interactivity. The author's background as an artist is prevalent in how empowerment via embodied interaction utilizing digital technologies (predominantly sensor-based [on-body/off-body] biofeedback mapped to digital multimedia [auditory, visual, robotic stimuli, etc.] and analogue content [video feedback, vocals, etc.]) was identified as a means to supplement traditional intervention in specific healthcare treatment programs and (re)habilitation.

Within the work a commercial industry startup was realized from the author's research, as well as international and national funded projects, and global acclaim as, e.g., plenary keynotes at leading international conferences, and more.

This contribution is focused upon sharing how in the 1990s, for approximately a decade, computer graphics were created as gesture-based interactive games under the author's gamification (including social interaction, creative expression, and enjoyable play) approach to healthcare and rehabilitation intervention. The core of the strategy is a catalyst fun experience from within an openly adaptive interactive environment that can be tailored for each participant profile and the treatment program goals. Most recently the work has realized a series of publications under the theme of "Technologies for Inclusive Well-Being."

Background

The work originated as an alternative contemporary avant-garde "human-at-center" art-related creative expressive form (i.e., "human-as-art"). Following numerous proof-of-concept and feasibility testing, early apparatus and method were realized in performances and exhibitions with positive reactions. In other words, the author-developed sensor-based bespoke systems were primarily explored within the author's work of own stage performances at numerous national and international festivals (including televised performances). These explorations included instances where he directed and produced (e.g., Cultural Paralympiad [Atlanta 1996 at Rialto Theatre]; Cultural Olympiad and Paralympiad [Sydney 2000 at Homebush arena]; European City of Culture [Copenhagen 1996 at Arken MoMA and Avignon 2000 at Cafe Nine]; Danish NeWave New York at Gershwin, 1999; Scandinavian Museums of Modern Art exhibition tours 1995–1999; and other "art-related" settings, e.g., Roskilde Festival 2000 and more). All instances were targeted as research resulting in ongoing learning of system limitations, potentials, and possibilities toward the envisioned applications beyond solely traditional "art" forms. In other words, in the majority of cases – for example, inclusive or adjacent to the above listed events – demonstration workshops, hands-on tutorials/seminars/symposiums, or other accessible showcase forms were arranged at the author's initiative to present the "alternative art" application, i.e., in healthcare, rehabilitation, and therapeutic training intervention. Such additional events offered increased research and learning opportunities including reviews, appraisals, assessments, and evaluations across disciplines, nationalities, and end users.

Bespoke Systems Overview: Leading to Patent - see Brooks and Sorensen (2005)

Overviewing and simplifying, the systems consisted of on-body and off-body systems that were experimented having differing biosensing profiles. Thus input was sourced ranging, for example, from inner-body micro-electrical signals, through limb or whole-body gestural position and motion dynamics, to spatial environmental signals where human occlusion or signal generation results in system input. Thus, human gesture attributes (proprioceptive, kinaesthetic, and related dynamics) and human state (being,

emotions, etc.) acted as input. Sourced input signals are routed to selectable software for mappings (scaling, filtering, etc.) to impact feedback responsive content (typically digital). This process routing of the data signals is managed to align desired relationships, i.e., interactive/reactive toward a goal of achieving flow, aesthetic resonance, self-agency, efficacy, and related idiosyncratic human attributes via afferent/efferent neural feedback loop closure. This causal loop closure is achieved through the process of optimally tailoring system attributes to human attributes, e.g., where the designed challenge is matching user satisfaction and sense of achievement. Individual end-user profile assessment can be either formal (with therapeutic input to realize targeted preset steps) or improvised (through system operator's – usually the author – experiences, so more impromptu adjustment of change parameters) to impact the system session design as experienced by a user. See Brooks Patent US6893407B1 on method and apparatus.

Embodied Interaction

The designed embodied interaction considered intent and non-intentional input as well as conscious and unconscious innate attributes. Through these means control and non-control have been experimented Brooks (2004, 2018).

Self-reflections and self-critique included from first-person and third-person experiences through which the system developed as a substantiated open and adaptive entity. As such the system (apparatus and method) enabled adoptions of various technologies as they appeared as both input interface apparatus and content toward optimizing a used model for treating a range of patients including those "born with" impairment or those who had "acquired" impairment either through accident, incident, or disease.

Experience as Product

A goal behind the "human-as-art" performative inquiries with the system was to realize a new instrument or tool that could supplement in and across rehabilitation and healthcare contexts. The concept was to explore creativity and play as motivational human modes attempting to make the experience of treatment/training more enjoyable, fun, and stimulating to participate within and less mundane, tedious, and boring. Once the system had reached certain maturity, further reflections and critiques resulted in system improvements that aligned with external professionals who evaluated from a formal and professional therapeutic perspective. Over the many years, the family and friends of users also evaluated – albeit in a more non-formal/informal context.

A motivational intervention (in-action) model and an (on-action) evaluation model were developed and published to support practicing professionals and/or home use by families and carers or even in self-use Brooks and Petersson (2005).

Exploring Nuances of Differences

An ongoing vision was of creating, utilizing, and exploring digital technologies to explore aspects of interactions such as nuances of differences that may be apparent through dysfunction compensatory requirements (e.g., an augmented sense of hearing/touch if a person cannot see). An evolving interest from this vision is in the exemplification and integration of such finite sensorial differences and how they can be represented and utilized within the art-related works for wide-audience education and enjoyment. In other words, and for example, how an "artist" with heightened sensory attribute (through loss of other sense) can represent such a sensory nuance so that audience members who are fully sensory loaded (thus, potentially, not as highly nuanced in a specific sense) may appreciate the art and be provoked to reflect on their educating of their evoked sense via the artwork.

This compensatory approach questioning comprehension of alternative channelling to augment training and other benefits from creatively expressing was apparently original within rehabilitation fields. For example, the applied research

with acquired brain-injured patients in a clinical setting questioned how a sense of proprioception (a participant's body sense of its parts and relative location to its other parts and the effort exerted in motion often related to balance and/or neglect) that was damaged could be "trained" through a patient *listening* to or *seeing* where their relative position of their own parts of the body are instead of *feeling* it. Additionally, patient dynamics of kinesthetic awareness of the position and movement of their parts of the body by means of their proprioceptors is targeted through programmable thresholds in the digital content algorithm according to a patient profile. Interactive computer graphics were thus engaged, alongside other digital content, as a means to visually inform a user of system input.

Afferent/Efferent Neural Feedback Loop Closure

Afferent/Efferent Neural Feedback Loop Closure: Proprioception and kinesthetic awareness are key aspects of the concept presented herein.

Literature informs that the central nervous system (CNS) receives sensory stimuli as (afferent) impulses external to the body. It then sends appropriate (efferent) instructions to a person's muscles and joints on how to react. The brain also receives some messages that cause the body to react unconsciously. Proprioception is a term referring to the internal messaging (the central nervous system) driving and controlling motion actions. Proprioceptors are sensors in human joints, muscles, and fascia, providing information needed to produce coordinated movement. Kinesthetic awareness refers to our ability to navigate space and the awareness of how we move. Kinesthetic awareness and proprioception work as partners to get us through the movements of our lives from the inside and the outside of the body. Muscle memory is a kinesthetic concept. So many things that we do without thinking – such as walking, whether we do it correctly or not – are kinesthetic experiences based on proprioception, which provides the awareness of our joints and body in space. Proprioception and kinesthetic awareness decrease after an injury – although, your brain will still have the skills stored within, so it is easier to relearn them. Even though your strength may come back easier, you will still need to spend time improving your proprioception and kinesthetic awareness so that you can fully recover.

By employing a system that responds to motion within an invisible space that can be controlled for data inhabitation and also mapping to digital content as stimuli offers opportunities in learning through feeling such as a sense of body position, muscle movement, and weight as felt through nerve endings.

Cognitive aspects are also involved.

Technologies for Inclusive Well-Being

Within the ongoing research, the art informs the design and intervention in rehabilitation in a cross correspondence such that the intervention also informs the art. This is aligned with reconceptualization, reframing, and cross-domain mapping as a bilateral approach that has been found effective in developing the research to the next level; however, that is not elaborated herein as it is a subject of another publication. Suffice to say that holistically, the research targets societal impact in (re)habilitation and healthcare under an umbrella titled "Technologies for Inclusive Well-Being" under which a number of publications have resulted with the author as lead editor. The next section introduces the author's gamification intervention approach.

Computer Feedback Training Under Gamification Approach

Near the time when biofeedback was being explored via worn sensor systems, audio-visual computer feedback and a series of robotic light devices were applied under a gamification approach to training in (re)habilitation and healthcare as outlined in the previous section. The purpose of this approach to supplement traditional approaches in intervention within training treatment programs was to engage the participant

to enjoy the training (vs. mundane, boring, and repetitive exercising without any self-reflective feedback that informs of progression).

Fun, Play, and Creative Expression Leading to Aesthetic Resonance

Fun, play, and creative expression are keywords in this approach that stimulate self-efficacy, self-agency, and a concept coined as aesthetic resonance that was the subject of European projects around the millennium (see Brooks 2011). In these externally funded projects, a focus was on creating systems where there was not the need for patient preparations such as careful positioning of sensors, the use of conductive gel to improve signals, and other invasive aspects. A patient could simply enter a space, set up an interactive environment, and move to manipulate digital responsive content. Initially the content was audio due to the used MIDI (Musical Instrument Digital Interface) signal protocol being native to communication within the music/sound domain. However, within the applied research sessions, it was clear that a wider selection of digital content to stimulate participants was required. Due to the author's background in mainframe computers (e.g. Honeywell TDC 2000), a decision was undertaken to investigate computer-based video games and interactive graphics (Figs. 1, 2, and 3).

Figure 1 illustrates interactive light gobos and Figs. 2 and 3 a "body paint" algorithm developed under a European project based on the author's research titled CAREHERE (Creating Aesthetic Resonant Environments for Handicapped, Elderly and Rehabilitation). The algorithm was used within the project and beyond, including in the author's annual workshop hosted by Casa da Musica, Porto, Portugal, which was a small part of a larger festival for disabled participants organized by the education team at the venue. Over a 2-week period, a variety of groups with differing profiles attended morning and afternoon (two workshops daily). Age ranged from young children to elderly and across the spectrum of dysfunction, both physical – including deaf, visually impaired, and wheelchair bound – and mentally challenged. Body painting was one of the activities whereby "digital paintings" were created as graphical images in the computer through participants' dynamic movements and then printed as an A3 picture. The pictures were exhibited as shown in Fig. 4 for the duration of the festival and given as gifts to the authors upon cessation. Notable was how, even though the pictures were in abstract forms, on return to collect their created artifact following the end of the festival, the participants each identified their own creation and collected it from the exhibition wall. It was astounding as there were no names visible for such identification of the computer graphics.

In this simple exercise, it was clear how a tangible outcome meant so much for the participants. When using auditory feedback, there is no tangible outcome unless a recording is made

Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 1 The author's gesture control of Martin Lights graphics – SoundScapes at Olympics and Paralympics, Sydney 2000 via three-headed infrared sensors mapping via MAX to DMX 512 via translation control interface

Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 2 Image of head and hand painting by PMLD participant

Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 3 Full-body painting based upon activity-level threshold mapped to color chart

and given on USB stick or download. The design was thus a success for participants and the organizing staff who attended with the groups. On return 4 months later for a conference, the leader of the elderly home for mentally challenged/dysfunctional attendees of the workshop informed that the institute organized an exhibition and oral presentation event so that the elderly could tell their own stories about creating their paintings. She explained how their motivation and inspiration had been stimulated to a highly positive degree such that their stories, unusually remembered compared to their other living detail, detailed aspects that her staff did not realize. She explained that it was a moving experience for the families who attended.

Soon after the mid-1990s, investigations of interactive animations and gamification within the SoundScapes research were conducted. This preceded the Personics interactive computer graphic environment that is introduced next.

Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being,

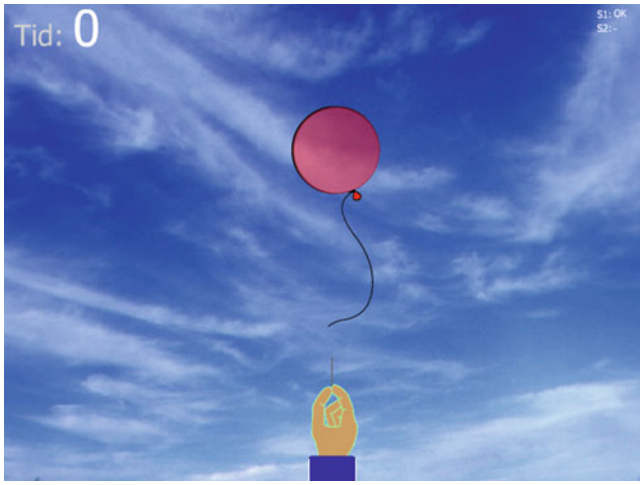
Fig. 4 Eyesweb body paint exhibition, Casa da Musica, Porto, Portugal

Personics

Experiments within the research led to a first simple "game" as an animation of an airplane that could take off, fly, and land with control via unencumbered gesture (i.e., no mouse, joystick, or keyboard). The reader should be aware that this experimental use of games controlled with gesture technology was before the pervasiveness of games and gesture control peripherals in the early 2000s.

The simple images on the following pages indicate the further explorations of basic interactive environments developed with the software Macromedia Flash (later Adobe Flash) as game content under the commercial company Personics as animated computer graphics as gamification in (re)habilitation therapy. The development was across the two funded aforementioned national and international projects having similar goals. In one case, the development followed input from the Humanics (the Danish government project) research team from the Center for Rehabilitation of Brain Injury [CRBI], this being where the clinical location of patient training was based at the University of Copenhagen. The team was working with acquired brain injury patients. Author-led roles in the project included conceptualizing, iterative design, leading intervention sessions, and communicating proposed designs and refinements with the development team, alongside testing and troubleshooting prior to sessions. The research personnel included a neuropsychologist, a psychologist, a cognitive psychologist, and a physiotherapist that worked under the Danish government *Erhvervsfremme Styrelsen* (Danish – translated as business development agency) who funded the research project titled Humanics for 9.5 million Danish Kroner (DKK). Another Danish government body, named *Satspuljen*, funded the project for an additional one million Danish Kroner (DKK).

Parallel to this project was the aforementioned international project. The background of this project is the research resulted in a European Union probe (under the European Network for Intelligent Information Interfaces – www.i3net.org). This was a funded project titled "The World Is As You See It" (TWIAYSI) – with the University of Bristol and a Swedish partner. TWIAYSI was developed into a European funded Framework V IST Key Action 1 project supporting the program for applications relating to persons with special needs including the disabled and elderly titled CAREHERE (Creating Aesthetic Resonant Environments for



Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 5 [Balloon] Computer graphic with gameplay receiving arm motion from the participant to reach and puncture the balloon with the pin in the animated hand. Time to complete the task in upper left

Handicapped, Elderly and Rehabilitation) Funding was approx. €2M.

Personics was invited by the author to participate in both projects.

Under the sponsorship of IBM at the World Congress for Physical Therapy (WCPT) in Yokohama, Japan, the author presented his research paper titled "Virtual Interactive Space (V.I.S.) as a Movement Capture Interface Tool Giving Multimedia Feedback for Treatment and Analysis" (Brooks, 1999).

Approximately a decade later, Hagedorn and Holm's (2010) independent randomized intervention study questioned traditional training versus computer feedback training (system resulting from author's research). This is reported in the *European Journal of Physical and Rehabilitation Medicine* where results state impact gains of up to 400% illustrate potentials from using selected games in Virtual Interactive Space as published in Brooks' 1999 paper. The 2010 investigation is introduced after the next section that presents the simple interactive computer graphics used.

Personics Computer Graphics

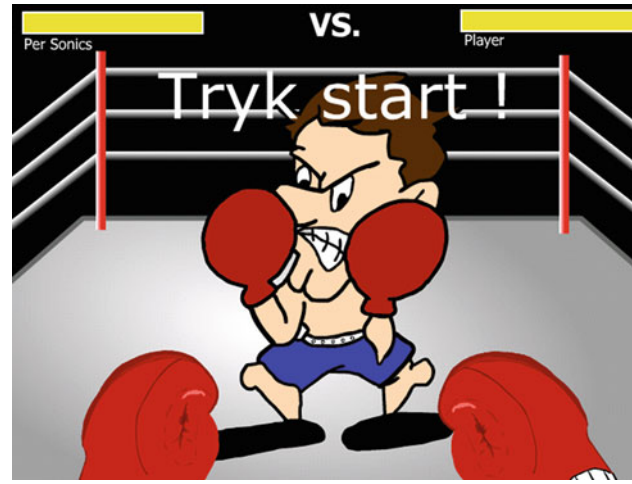
The following images represent the gameplay graphics. Notes attempt to describe the gameplay and target in the therapeutic sessions with bmp screenshots depicting start screen and interactions.

Figure 5 illustrates a balloon game concept where a sensor is placed at a specific location according to therapist input. In Hagedorn and Holm (2010), balance training exercise was for each patient to alternate between normal standing balancing and toe-standing balancing. Balloons were popped when each cycle was completed within the sensing space. Duration of training depended on patient endurance. The number of balloons popped gave indication of training effort.

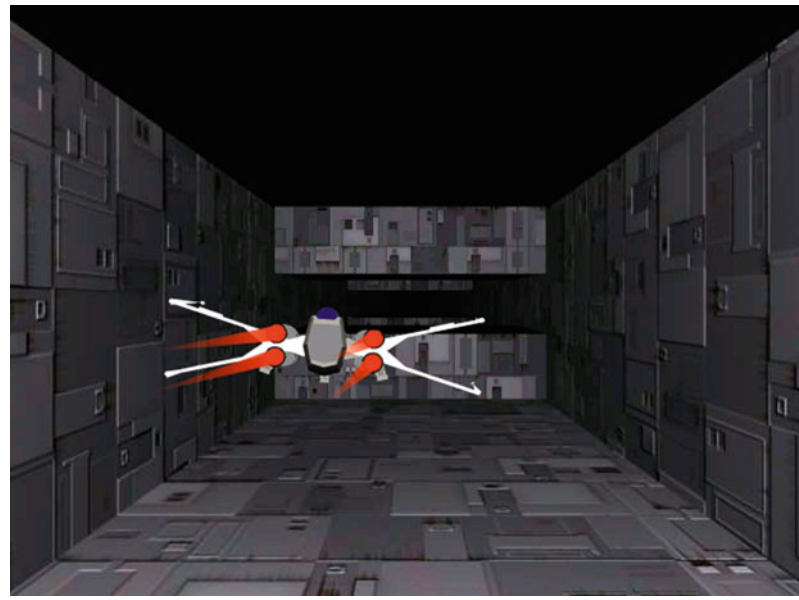
Figure 6 was a boxing game tracking the patient's two hands (mapped to the lower boxing gloves). Scores were archived according to performance.

Figure 7 was a game where the navigation of a Death Star fighter (Star Wars) was controlled by patient movement. Guidance through a maze was tasked.

Figure 8 was a Dolphin wireframe model that was mapped to two sensors representing horizontal and vertical travel. This is used successfully in the CRBI research where a therapist controlled one sensor and a patient controlled a second sensor. Progression for the patient was to use both sensors to control the full travel of the dolphin. Time was recorded for each level and a number of fish caught. Levels were progressively more difficult whereby lethal jellyfish had to be eluded.



Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 6 [Boxer] A two-handed exercise where sensors detect dynamic motion of each hand, which are mapped to left and right boxing gloves to strike opponent who is able to guard and strike back



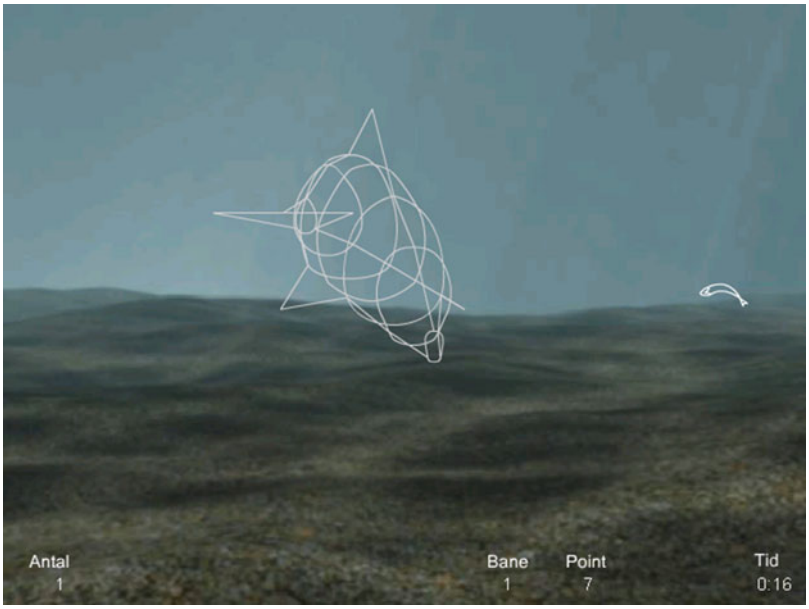
Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 7 [Death Star] Flight simulator where participant motions control up-down (y-axis) and left-right (x-axis) of Death Star fighter vehicle to prevent crashes and to reach targeted goal

Figure 9 was used to task the patient in dynamic motion aligned with a weightlifter raising a dumbbell. Dynamic of motion was tracked within the sensing field.

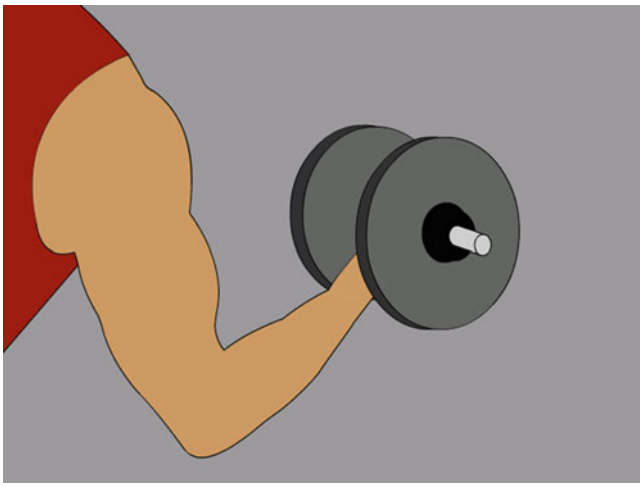
Figure 10 was themed from the Mission Impossible film where a diamond was stolen. Patient activity was through three sensor fields that would activate, deactivate, or alarm the system. The mapping of this game was mostly found to be too complicated for most patients.

Figure 11 illustrates another dynamic motion computer graphic. In this case the patient's hand motion had to exceed a threshold in order to let go of the ball. This proved a favorite exercise for acquired brain-injured unilateral neglect or hemispatial neglect patients training a damaged side.

Figure 12 illustrates the tower that was one of the animated games used in the Hagedorn and Holm (2010) study with balance elderly patients. The number of blocks and difficulty could be changed and archived. Feedback of balance in training was where one leg was lifted from the ground – as in stepping actions associated with



Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 8 [Dolphin] Wireframe dolphin travel controlled by two sensors mapped to x-axis and y-axis to catch and eat the dead fish dropping from top of the screen while escaping hazards on each level



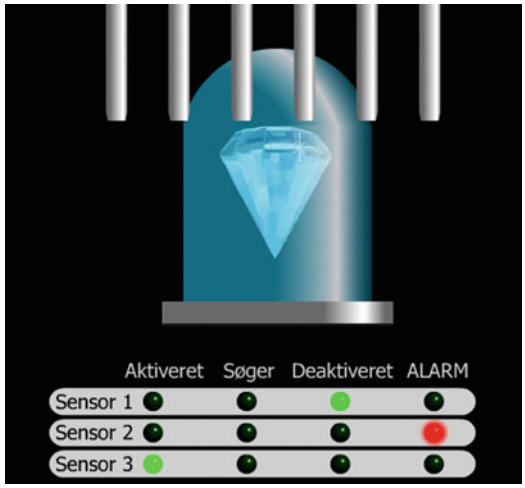
Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 9 [Dumbbell] Sensors capture participant lifting motion dynamic and range to raise a corresponding animated dumbbell held by a weightlifter

walking activity within the sensing space. The height of the built tower indicated training effort. Both legs were trained.

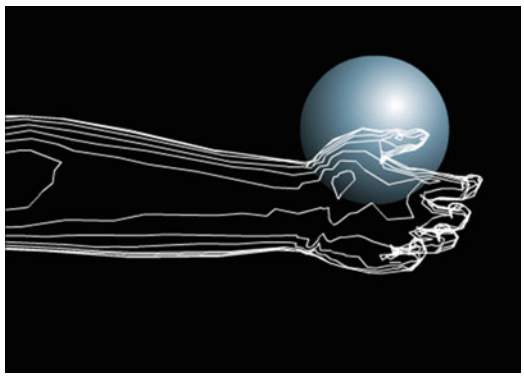
The waiter tray game, as illustrated in Fig. 13, was also used in the Hagedorn and Holm (2010) study. Sensors captured body position and adjusted the tray angle accordingly. Patients stood on a firm plate, which was placed upon a 5 cm depth of dense foam. The numbers of broken glasses were recorded in each session of 2-min duration. A session consisted of two instances of training where both data were included for analysis. Physical level-of-difficulty adjustments took the form of a thicker foam plate that could additionally be changed for a tilting board; also glass friction and plate size were adjustable.

Figure 14 gives a direct feedback to a patient's balance according to a horizontal line that was required to line up to the central division in the graphic.

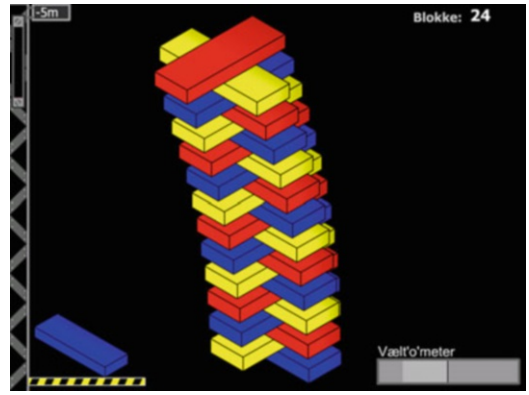
The fourth game used in the training was where balance controlled the position of an animated empty basket to catch images of fruit falling from a tree. Healthy fruit was collected, while



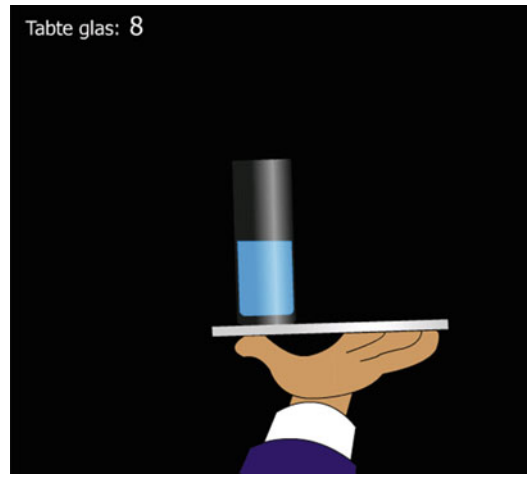
Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 10 [Migame] Mission Impossible task where three sensors are used tracking participant motion to deactivate alarm to raise the glass dome and reach the diamond target



Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 11 [Throw] Training for a damaged arm (such as in acquired brain injury) where motion sensors track dynamic of throw gesture. With sufficient dynamic the hand releases the ball



Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 12 [Tower] Motion sensors detect the moving of virtual blocks from a storage space to an adjacent position in order to create a tower

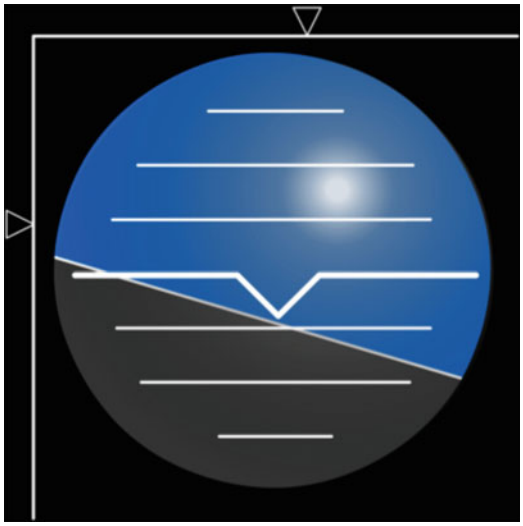


Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 13 [Waiter] A balance game where weight on the right or left foot determines the inclination of the waiter tray. The goal is to keep the glass on the tray and train dynamics. Tray size and friction coefficient can be adjusted

rotten fruit was not. Each incremental level had increasing speed of fruit falling.

Discussion

Eber (1997) reflects how a work of art, according to Tolstoy (1995 [1897]), is sincere, and it transmits feelings through lines, colors, sound, or words. The feelings embedded in the imagery start with the creator and the creative process. The work may take any form, but to be art, the object, idea, or installation goes beyond the physical and contain some form of human experience. Art may be created with any tool, as long as the artist rises beyond that tool into an experiential realm. Many



Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being, Fig. 14 [Balance] Motion sensors combined to perform as a mouse emulator driven by weight distribution. The goal of the participant, typically with acquired brain injury, was to position the dividing horizontal line along the central balance. Arrows on the y-axis and x-axis act as guides

have debated the existence of the creative domain with the computer art medium, especially virtual environments (VE). With the tools to create a VE, the artist will learn a new technology that may influence the nature of and how she reaches the creative level (see Eber 1997).

According to Eber (1997), in addition to the acquisition of new information, the artist who chooses to work with VEs also has a new set of aesthetics to consider, as the final work of art is wholly different from that using any other medium. Contrary to the concepts expounded in the popular media, a VE art installation can be more than a display arena for the art of others (e.g., Picasso) or a "shoot 'em up" computer game. It can be a work of art in and of itself, one that requires of the artist the same level of abstraction into the spirit of creativity as any traditional medium demands. How and at what point does the creative process happen for a VE artist in a world of computer peripherals and code?

Further Eber (1997) states how an art installation is a work of art that goes beyond an object that exists on a wall or behind a glass but encompasses an infinite number of artistic possibilities including alternative presentations, environmental constructions, multisensory stimulation, viewer interactivity, and theatrical performance.

This text presents a historic perspective of the research alongside a review of the basic computer graphics that resulted. The purpose of the text is to share the narrative while attempting to inspire next-generation researchers. The goal to inspire targets championing others to persevere against adversity, often when being mocked when pursuing one's original concept, in this case a concept that resulted in national and international funded projects, a patented method and apparatus, commercial industry product, and company start-up.

Early studies explored solely auditory stimulus as a feedback to user input. Initially the means of input was hardware-based rocker control pedals as typically used by musicians for altering instrument output, e.g., guitar. Subsequently, user biofeedback signals were sourced either via on-body or off-body sensing interfaces with differing profiles. Such profiles have increasingly advanced over the years of the research such that original interfaces are no longer viable when compared to affordable and available computer game peripherals and camera-based solutions.

However, the "communication method and apparatus" patent has been referenced 16 times, including 12 by the patent examiner.

A further example of impact is an independent investigation of product resulting from this research in a randomized intervention study by Hagedorn and Holm (2010) comparing conventional balance training against computer feedback training with older people. The randomized controlled 12-week intervention trial was designed on pre- and post-training evaluations conducted on 35 outpatients of a geriatric falls and balance clinic. Responsive computer graphics, with a variety of selectable game themes, responded to input motion sensors.

Results were reported of 400% improvement in specific performance; however, in the author's opinion, the industry is still lacking behind

in training trainers to fully optimize such results within a wide range of interventions so as to benefit societally via transfer to activities of daily living (ADL).

Conclusion

This article shares insight of avant-garde art with societal impact that has been recognized by third-party researchers and educators as pioneering the use of digital technologies with differently abled. A focus has been on illustrating the simple computer graphics used as mappable content to give feedback selectable from an array of stimuli. This text informs how the healthcare rehabilitation informs the art and correspondingly how the art informs the healthcare rehabilitation.

The use of multimedia responsive feedback to human input indicates how art (creative expression) and play (enjoyment and fun) have an important part to play in both physical and cognitive therapy (re)habilitation. While extended range and dynamics of motion (body, limb, etc.) are quantifiable, it is also evident through the comprehension of designed interactions by profound and multiple learning disabled (PMLD) how the concept has potentials beyond what has already been reported.

To sum up and in accord with these conclusions, it is important to point out how it is increasingly evident that improved systematic evaluation is needed in this field to define the specific use benefits of (computer graphics as) video games in healthcare and rehabilitation intervention. Aspects of such evaluation are proposed as incorporating increased duration and control of trials with improved measurements (randomization, blinding, etc.) and consistency of measurement tools across investigations including beyond actual treatment programs to embrace impact on activities of daily living (ADL). However, innate to such a proposal are the ongoing challenges of individual human differences that many may consider immeasurable; yet, for improved research and impact comprehension, it is important to target optimized research validity and reliability in order to advance and educate.

Notes The figures (5 – 14) are from the author's own archive from employment. All efforts to get permission have not been responded upon and it is understood that the company was closed shortly following the author's departure and copyright ownership is not listed for these images. Acknowledgement made in this chapter for the authors of the images created under the company Personics who do not name or credit authorship.

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Computer Vision

► Fall Risk Detection in Computer Vision

Computer Weiqi

► Computer Go

Computer-Aided Design (CAD)

► Imagineering Ceramic Pottery Using Computer Graphics

Computer-Aided Industrial Design (CAID)

► Imagineering Ceramic Pottery Using Computer Graphics

Computer-Mediated Reality

► History of Augmented Reality

Computing for Smart Toys

► Toy Computing

Concatenative Sound Synthesis

► Dynamic Music Generation: Audio Analysis-Synthesis Methods

Conceptual Blending

► Foundations of Interaction in the Virtual Reality Medium

Conceptual Model of Mobile Augmented Reality for Cultural Heritage

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Synonyms

Augmented reality; Enjoyable informal learning; Mobile augmented reality for cultural heritage; Mobile augmented reality

Definition

Conceptual model of mobile augmented reality for cultural heritage towards enjoyable informal learning is a representation that provides, by a composition of concepts, component of content, navigation and user interface design, interactivity, features, hardware, and process that is appropriate for enjoyable informal learning at cultural heritage site for mobile augmented reality.

Introduction

Mobile augmented reality (AR) for cultural heritage site has been developed for already a decade (Angelopoulou et al. 2012; Armanno et al. 2012; Chang et al. 2015; Ciurea et al. 2014; iTACITUS 2007; Kim and Park 2011; Moorhouse et al. 2017; Seo et al. 2011; Techcooltour 2013; Tussyadiah et al. 2017; Vlahakis et al. 2002). However, these existing applications lack enjoyable informal learning concept (Damala 2009).

Enjoyable informal learning is based on interpretation theory (informal learning in cultural

Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Table 1 Frequency of responses of expert review

Items	Needs very detailed explanation	Needs some explanation	Is easy to understand	Didn't respond	Total
1. Clarity of terminology					
(a) Content structure	0	2	3	2	7
(b)Theory	0	2	3	2	7
(c) Mobile technology	1	1	3	2	7
	Some are definitely not relevant	**Some may be not relevant**	**All are relevant**		
2. Relevancy of proposed components					
(a) Media elements	0	0	5	2	7
(b)Activity	0	0	5	2	7
(c) Navigation	0	0	5	2	7
(d) Social interaction	0	2	3	2	7
(e) Games	0	1	4	2	7
(f) Presentation style	0	0	5	2	7
(g) Mobile technology	0	1	3	3	7
	Not relevant	**Relevant**			
3. Relevancy of proposed theories	0	5		2	7
(a) Multimedia learning theory	1	4		2	7
(b) Mindfulness theory	0	5		2	7
(c) Constructivism theory	0	5		2	7
(d) Situated learning theory	0	5		2	7
(e) Experiential learning theory	0	5		2	7
(f) Collaborative learning theory	0	5		2	7
	Yes	**No**			
4. The connections of all the theories and components are logical	3	1		3	7
5. The conceptual model is usable for the development of mobile AR for cultural heritage toward enjoya ble informal learning	4	0		3	7
6. In overall, the conceptual model is readable	4	0		3	7

heritage) and enjoyment theory. Enjoyable informal learning enables visitor not to feel he/she is learning, but at the same time, he/she is achieving new knowledge (Ariffin 2009). However, the existing mobile AR for cultural heritage site lack major components in enjoyable informal learning, namely, navigation and user interface, quality of content, use of questions, and physical orientation (Bellotti et al. 2002; Moscardo 1996). This is critical as it can make the usage of mobile AR as interpretive media to help visitor to learn at cultural heritage site is far from being practical.

Therefore, this entry shows how a conceptual model, which provides component for enjoyable informal learning at cultural heritage site (Pendit et al. 2014), can be used to design AR applications for cultural heritage sites. A conceptual model represents the key concepts and provides accurate, consistent, and complete representation of concepts (Churchill 2007; Norman 2014). It helps developer to develop mobile AR that implements enjoyable informal learning at cultural heritage site that enable visitor to learn at cultural heritage site in enjoyable way. It helps developer to develop mobile AR that implements enjoyable

Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Table 2 Feedback from experts

Experts	Comments
Expert 1 (Spain)	(a) Divide "media elements" into two types: passive and active content. Active content is the content that includes user interaction, such as: activity, social interaction, and games
	(b) More details on the theory to understand their relevancy on supporting the content structure
	(c) Put elements in mobile technology into categories: "core technologies for AR" and "necessary devices for AR." The terms "sensor" and "mobile technology" are also not proper
	(d) Add "taking picture" and "interacting with content" in the "Activity" component
	(e) The term "chat" in social interaction is not proper
	(f) Add virtual views in the presentation style
	(g) Strength: the conceptual model is feasible and worthwhile to improve the informal learning experience at cultural heritage site
	Weakness: Most of components have been presented in previous works and novel components in informal learning are not sufficient
	(h) Add details for each component in hierarchy or layers than list the individual elements
	(i) Validate the conceptual model through user evaluation
Expert 2 (France)	(a) Add more detail explanation on content structure and theory
	(b) Relationship between components in "mobile technology" is not understandable
	(c) Add category for different "function" of component and add "Display" component
	(d) "Activities," "navigation," and "manipulation" can be added as well as "activity" related to media elements: "see and hear" in activity component
	(e) Add "navigation for museum and indoor cultural heritage environment."
	(f) Add shared view with single display in social interaction
	(g) Provide other type of games: 3D puzzle
	(h) Provide more explanations in "presentation style"
	(i) MLT theory and collaborative learning theory should be linked to other elements in the content structure
	(j) Mindfulness theory should consider personal cognitive style and traits of visitor that may influence the social interaction. Constructivism theory, situated learning theory, and experiential learning theory should be linked to media elements
Expert 3 (Spain)	(a) Consider HCI theory as AR system should be interactive in real time (Azuma 1997)
	(b) Differentiate between audio and sound in media elements. Also distinguish different types of object: static and dynamic. The elements also can respond to user interaction
	(c) Consider providing a complete map of the site and recommended route for the visit in navigation
	(d) Clarify the term "chat." Differentiate between virtual and real (face to face) interaction in social interaction
	(e) Clarify the term "separated augmented view" in presentation style
	(f) Add category for different function of each mobile technology component, such, hardware, software, and process
	(g) Conceptual model is well presented and logical. However, it misses the term "interaction" as it is a fundamental part of AR system. The mobile technology component also needs to be better presented
	(h) Consider to add validation/evaluation component in content structure on evaluating the learning process
Expert 4 (Taiwan)	The proposed model is thorough and detail. I expect the outcomes of this model would be good if the learning activities can be well-arranged
Expert 5 (USA)	(a) Useful conceptual framework to inform the design. Mindfulness theory is not familiar but others are well aligned with the teaching and learning methods possible through AR
	(b) The missing major element is the outcome of the variable that will be measured
Expert 6 (Malaysia)	(a) Proposed elements in content structure are too generic and are applicable to any kind of applications
	(b) Connections of all theories ad components are somewhat logical
	(c) The conceptual model is partly usable to the development of AR for cultural heritage toward enjoyable informal learning
	(d) The conceptual model is too brief
	(e) Expand and detail out specifically about AR and cultural heritage
Expert 7 (Malaysia)	The conceptual model is good but the scope is too wide that it should focus more on enjoyable learning

informal learning at cultural heritage site that enable visitor to learn at cultural heritage site in enjoyable way. Since the conceptual model has been developed (Pendit et al. 2014), it was then evaluated and revised through series of evaluations, expert review, field study of enjoyable informal learning, focus group discussion, and review of related conceptual model of mobile AR for cultural heritage site and mobile guide. After all those evaluations, the conceptual model

Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Table 3 Findings of field study of enjoyable informal learning content at cultural heritage site

No.	Category	Responses
1	Preferences of media	Image, animation, and video
2	Text	a. Show point by point
		b. Provide big size of font
3	3D model	Overlay certain part that is lost
4	3D character	Represent the noble people in the past
5	Image	a. Overlay certain part that is lost
		b. Old pictures with year in chronological order
6	Audio	a. Provide history of cultural heritage site
		b. Provide history of cultural heritage site in storyline
		c. Provide history of cultural heritage site in storyline and the narrator has the same age with visitors
		d. The length of audio should be in 3–5 min
7	Sound	Provide ambience of heritage site
8	Animation	a. Provide history of cultural heritage site with the noble people as the character in storyline
		b. Length of 3D animation is 5–10 min
9	Video	a. Provide video of cultural heritage site with noble people as the character
		b. Provide video of cultural heritage site with noble people as character in narrative storyline
		c. Provide video of cultural heritage site with the noble people as the character in the storyline and the narrator should be of same age with visitors
		d. Length of video is 5–10 min
10	Preferences to learn based on interest	No, it is not preferable to learn based on interest
11	Navigation	a. Show other interesting places around the cultural heritage site
		b. Show the route visitor had visited
		c. Show the site based on history in chronological order
12	Activity	a. Add/edit information
		b. Take picture
		c. Create notes
13	Games	a. Brain games
		b. Adventure games
14	Interaction	a. Shaking
		b. Blowing
		c. Rotating
15	Preferences of AR	a. Take picture wearing the costume of noble people using AR technology
		b. Take picture with the events of the past using AR technology
16	Things make visitors enjoy at cultural heritage site	a. Relax
		b. Fresh air
17	Other features	Music

was finally finalized which are presented in the end of this entry.

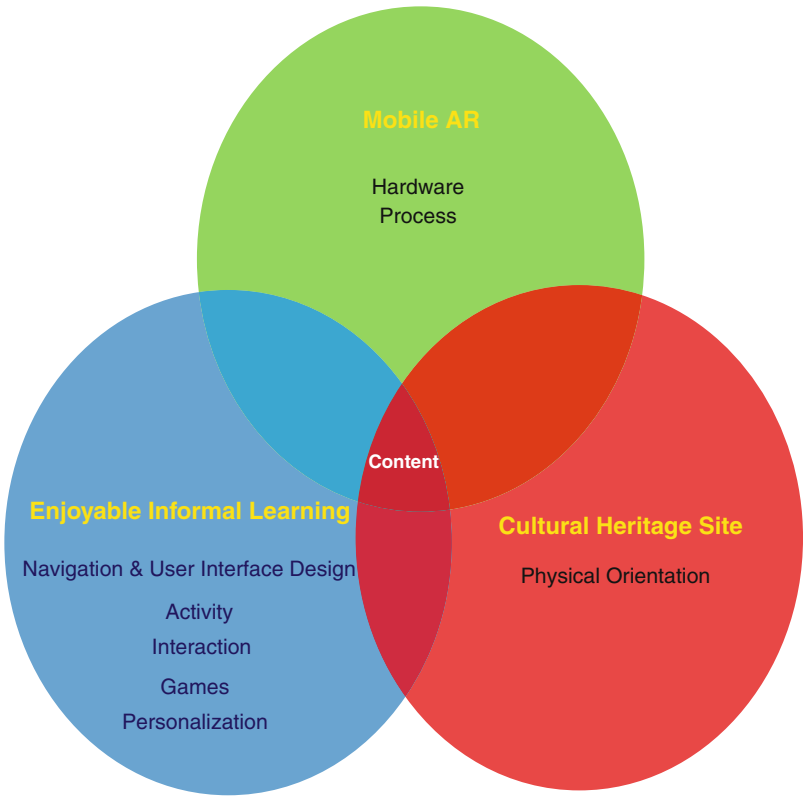
The topics of this entry are consisted in four sections, which are introduction, methodology that tells about validating the conceptual model, the revised conceptual model that becomes the result of validation, and finally, at last, the conclusion of the study.

Methodology

Basically, the conceptual model has validated through two steps: expert review and focus group discussion. Expert review involved seven experts to validate model based on review form through email communication. After the expert review, before continuing with the focus group discussion, the researcher embarked on a field study of enjoyable informal learning content at cultural heritage site in order to respond to review of expert on the novelty of component of conceptual model. Then, after the component of conceptual model was reviewed based on user requirement of enjoyable informal learning content from field study's result, it was sent to focus group discussion. The focus group discussion validated the model by joining seven experts. Then, after it has been evaluated in focus group discussion, an activity called review of the conceptual model of mobile AR for cultural heritage site and review of mobile guide was completed to act in answering focus group discussion's feedback about the component of conceptual model. The result from the review was applied in revising the conceptual model of mobile AR for cultural heritage site toward enjoyable informal learning. At the end, the final version of the conceptual model was produced.

Expert Review

In validating the conceptual model, expert review was conducted. There were seven experts who had reviewed the conceptual model with criteria of teaching AR/human computer interaction/



Conceptual Model of Mobile Augmented Reality for Cultural Heritage,
Fig. 1 Overview of conceptual model of mobile AR for cultural heritage site toward enjoyable informal learning

Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Table 4 Comments from focus group experts

No.	Comments
Expert 1	a. Include informal learning theory
	b. Emphasized on interactivity and enjoyable informal learning for content element component
	c. Connection in conceptual model could not be seen
	d. Focus more on enjoyable informal learning and the main contribution of conceptual model
Expert 2	a. Theories are relevant but have to be presented more clearly
	b. Add informal learning theory
	c. Consider "tangible AR" for terms
	d. Add interaction component
Expert 3	a. Connect the mobile AR technology and content element component
	b. Add more elements in content element
	c. Create general model to be used for other field related with mobile AR or enjoyable informal learning or cultural heritage site
Expert 4	a. Connection between all components should be improved
	b. Focus more on enjoyable informal learning
Expert 5	a. Mobile AR technology component should be improved
	b. The terms should be improved
	c. The connection between mobile AR, theories, and content element is not clear
	d. The conceptual model is not clear enough
Expert 6	a. The theory should be reconstructed in order to be understood
	b. Consider to combine content element with mobile AR technology
	c. Some terms are not clear, such as, "provided for each site"
	d. Combine all components with mobile AR technology
	e. Differentiate the uniqueness of mobile AR technology component from the existing one
Expert 7	a. Add one element special for cultural heritage site in content element
	b. Connection between theory and content element seems logical
	c. The term "registration" is not clear
Expert 8	Create general model consists of three main topics: mobile AR, enjoyable informal learning, and cultural heritage site

multimedia with minimum 5 years of experience. The expert was given a copy of proposed conceptual model with the form that contains check list of items and elements of conceptual model. The thoughts from the experts said that conceptual model had terminology that was easy to understand (refer to Table 1). This also applies to the proposed components which are relevant. Overall, experts concluded that the conceptual model is usable in the development of mobile AR for cultural heritage site toward enjoyable informal learning.

The next result displayed written comments which were sent by two experts who did not fill up the form and other five experts who filled up the form (refer to Table 2). Three experts addressed the mobile technology component. They suggested mobile technology should be provided by category to divide different functions of each element. Furthermore, they also added some elements in the content structure component and changed the terminologies. Some comments were changed in terms of diction but the meaning of comment was maintained.

The review was taken into consideration in revising the conceptual model. In addition, one particular comment which mentioned about lack of conceptual model of novel component of enjoyable informal learning was responded by conducting a field study of enjoyable informal learning content that is elaborated in the following section.

Field Study of Enjoyable Informal Learning Content at Cultural Heritage Site

In response to the feedback from expert, a field study was conducted at Lembah Bujang Archaeological Site, Kedah. The purpose is to gather user requirements about content of enjoyable informal learning at cultural heritage site and to define novel components of proposed conceptual model. The questions were taken from the component of conceptual model, the literature, and expert's feedback. In total, there were five participants from targeted ten participants from 17 to 49 years old who participated in the study. The numbers of participants are relatively enough as the researcher has attained similar answer from all participants (Creswell 2012).The questions are in Malay and English language. They are related to

Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Table 5 Component and element of conceptual model

Component	Description	Element	Implementation
Hardware	Physical components needed for developing mobile AR for cultural heritage toward enjoyable informal learning	Handheld devices	Smart phones
			Tablet
Process	Steps or actions needed to develop mobile AR for cultural heritage site toward enjoyable informal learning	Reconstruction	Reconstruct wall of A Famosa into 3D model by using 3DsMax
		Registration	Align virtual object of wall of A Famosa in the real world by tracking user's position and orientation of user's view
		Tracking	Find location of user by using sensor-based tracking, vision-based tracking, and hybrid-based tracking in A Famosa
		Rendering	Generate virtual object/scene and present it to the real environment of A Famosa
		Interaction	Shaking, blowing, rotating, leaning, and nodding the mobile phone and user's head to retrieve information about A Famosa
Content	A set of media representation which consists of criteria that can be a guideline to provide enjoyable informal learning content at cultural heritage site	**3D model** Overlay certain part that is lost	Reconstruct the lost wall of A Famosa to 3D model
		3D character Represent noble people in the past and act as virtual guide	Alfonso d'Alburqueque, Captain of Portuguese, as 3D virtual guide at A Famosa
		Text Provide description in point by point	Profile of cultural heritage site that contains information about history and background information of cultural heritage site
		Image Overlay certain part that is lost	Old picture of the wall of A Famosa, old picture of A Famosa, overlay picture of Alfonso d'Alburqueque, and old picture of war between Portuguese and Dutch at A Famosa
		Provide old picture about the site, noble people, and events	
		Audio Recorded audio presented by narrator who has the same age with visitor	Story that tells how A Famosa was built by Portuguese
		In-depth and special information in 3D animation and video	
		Provide audio with maximum duration in 5 min	
		Sound Provide ambience of the site in the past that can help visitor imagine how the site was	Sound of bomb during the war
			Conversation between inhabitants
			Sound of captain's car

(continued)

Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Table 5 (continued)

Component	Description	Element	Implementation
		Animation	Story about how the war between Portuguese and Dutch long time ago happened in A Famosa
		Provide in-depth and special information in storyline	
		Use noble people as character	
		Provide animation with maximum duration in 10 min	
		Video	Story about how the war between Portuguese and Dutch happened in A Famosa long time ago
		Provide in-depth and special information in storyline	
		Use noble people as character	
		Provide video with maximum duration in 10 min	
		Push content The type of content that appears automatically when visitor reaches certain area	All elements of content
		Pull content The type of content that should be retrieved	All elements of content
Navigation and user interface design	Navigation and user interface design that helps visitor to learn in enjoyable way at cultural heritage site	Provide thematic path	Provide theme of cultural heritage site based on colonialism era (Portuguese colonialism, Dutch colonialism, British colonialism)
		Provide layered information	Provide description about the structure and construction about A Famosa and continued by history of formation of A Famosa
		Provide one-tap access for frequent menu	Provide "home" button for accessing the menu
		Provide one-handed control	Provide one-handed control for the navigation
		Provide clue for scene with augmented content	Provide clue in balloon to tell there is augmented scene in the area
		Provide shaped button	Provide play button in its shape in order to make visitor easy to access
		Provide quick button to go to main menu	Provide "home" button to the information menu to go to homepage quickly
		Provide big size of font	Provide big size of font on the interface
		Provide appropriate size of content	Provide three-fourth content size for the page
		Provide enough contrast between text and background	Provide white background for black text

(continued)

Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Table 5 (continued)

Component	Description	Element	Implementation
Interactivity	Activity: a set of activities that can trigger the whole learning process at cultural heritage site by integrating the visitors, learning material, and learning environment	Take picture	Provide option to take picture of A Famosa
		Share information	Provide option to share information of A Famosa to social media (Facebook and Twitter)
		Edit/add information	Provide option to add or edit information of A Famosa
		Create notes	Provide option to create notes about experience of visiting A Famosa
		Save information	Provide option to save the information of A Famosa to personal device
	Interaction	Shaking	Enable visitor to shake their phone in order to retrieve the information about A Famosa
		Blowing	Enable visitor to blow the wall of A Famosa to retrieve the information
		Rotating	Enable visitor to rotate their phone to left or right in order to turn the 3D object to the preferred direction
		Leaning	Enable visitor to lean or move the 3D object to left or right
		Nodding	Enable visitor to move the 3D object up and down by nodding his/her head
Features	Personalization: a set of options that can be chosen by visitors in order to display the right content to fulfill their needs	Historical period	Enable visitor to select the cultural heritage site in the range of 1819–1900 or 1901–present
		Interest	Enable visitor to choose the cultural heritage site to be visited based on personal interest
		Range of distance	Enable visitor to select the cultural heritage site within the range (0–5 km, 6–10 km, and 11–15 km)
		Language	Enable visitor to choose the language based on their preferences
	Games: the type of games that help visitor to refresh, stimulate, and make them understand the history	Adventure games (treasure hunt)	Treasure hunt games about history of A Famosa
		Multiple choice quiz	Multiple choice question about history of A Famosa
	Physical orientation: is a set of functions to guide visitor while learning at cultural heritage site orientation	Showing the surrounding interested places	Show other cultural heritage site near A Famosa
		Showing recommended route to the site	Show the route from airport to A Famosa, enable the visitor to search location of A Famosa
		Allowing direction inquiry	Allow visitor to search for route

(continued)

C

Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Table 5 (continued)

Component	Description	Element	Implementation
		Showing direction with virtual arrows overlay on real path	Show direction to A Famosa with virtual arrows overlay on real path from Saint Paul
		Showing map of the site and location of visitors within the site	Show the map of A Famosa and location of visitor within A Famosa
		Showing provided content	Show the provided content in A Famosa
		Showing visited route	Show the visited route at Melaka Heritage Site
		Showing the current position	Show the current position of visitor

the content that is appropriate for learning in enjoyable way at cultural heritage site, including: types of media, navigation, games, activity, and interaction. In total, there were nineteen questions in total with fifteen multiple choice questions and two open-ended questions. The researcher did the field study by approaching random visitors and interview them about the questions while at the same time demonstrating mobile AR feature mentioned in the question. The responses from participants are provided as follow (Table 3).

Focus Group Discussion

Focus group discussion was conducted to evaluate the conceptual model. There were seven experts who had participated in the focus group. The experts were all from Malaysia, and they should be those have been teaching AR/HCI/Multimedia/Media Studies with a minimum of 5 years of experience.

The focus group was started by presentation about the conceptual model. Then experts were asked to review the conceptual model based on the criteria in the review form (refer to Fig. 1). During the discussion, experts were also allowed to ask questions. The process of discussion lasted for one and half hour. It was a beneficial discussion. The result is provided in Table 4.

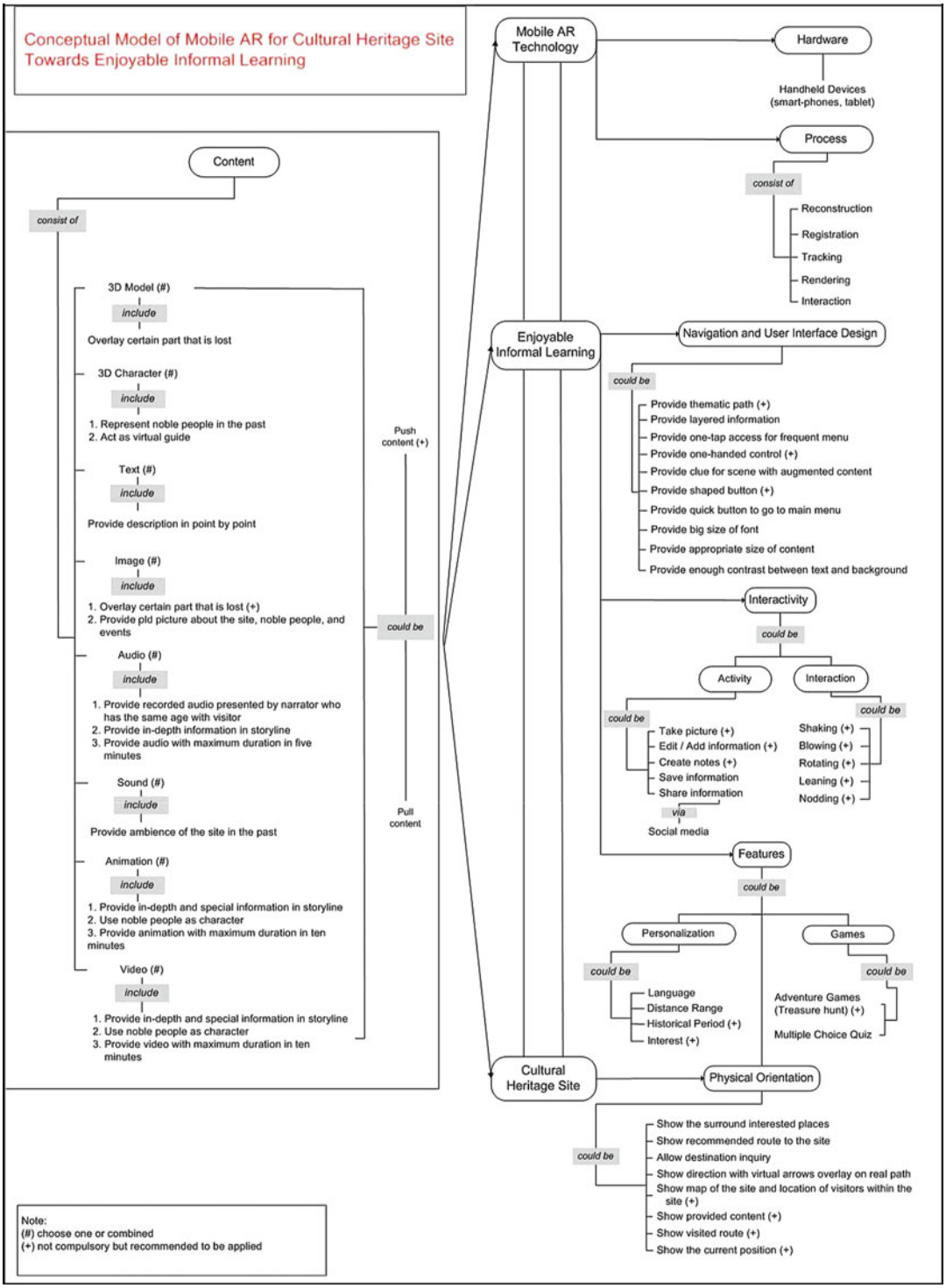
The Proposed Conceptual Model of Mobile AR for Cultural Heritage Site Toward Enjoyable Informal Learning

After all the validation process, the conceptual model was comprised to be finalized. There were six components and twenty-nine elements that is included in the conceptual model based on the validation (refer to Fig. 2). The explanation about component and element of conceptual model is provided in Table 5.

The conceptual model focuses on enjoyable informal learning. However, it integrates existing three main fields: mobile AR, enjoyable informal learning, and cultural heritage site (refer to Fig. 2). This becomes the uniqueness of conceptual model that is not implemented in the existing conceptual model. The proposed conceptual model is displayed.

Conclusion and Discussion

This study has produced a conceptual model of mobile AR for cultural heritage site towards enjoyable informal learning. The model comprises three structures, six components and twenty nine elements. The structures represent the main topic of conceptual model, which are, mobile AR, enjoyable informal learning, and cultural heritage. The component presents the



Conceptual Model of Mobile Augmented Reality for Cultural Heritage, Fig. 2 Revised conceptual model of mobile AR for cultural heritage site toward enjoyable informal learning

main component that are appropriate for conducting enjoyable informal learning at cultural heritage site, which are, content, navigation and user interface design, interactivity, features, hardware, and process. Lastly, the elements of content component are the backbone in realizing enjoyable informal learning.

The conceptual model aims to help developer in developing mobile AR for cultural heritage site toward enjoyable informal learning. It can be implemented to any platform, to a whole domain (mobile AR for cultural heritage site toward enjoyable informal learning), and to each domain (mobile AR, enjoyable informal learning, and cultural heritage site). Furthermore the conceptual model is also hoped to be used and to make a lasting impact onto the existence of cultural heritage site.

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Constrained Edges and Delaunay Triangulation

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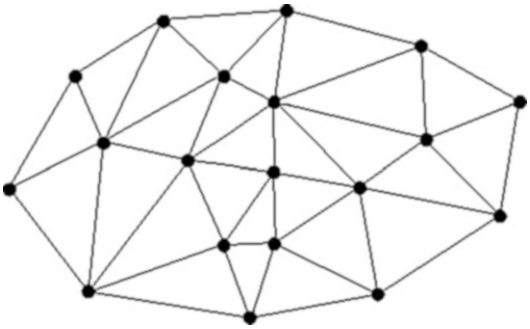
Synonyms

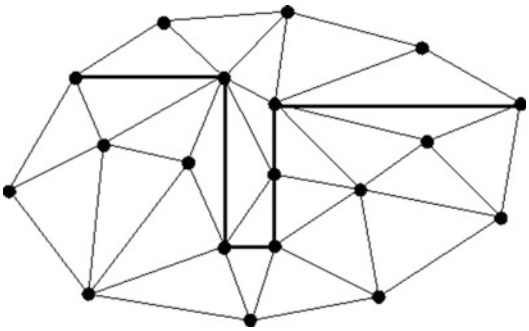
Delaunay tessellations; Delaunay Triangulation; *Delone tessellations*

Definition

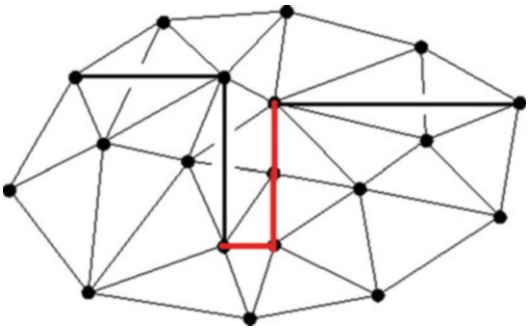
A Delaunay Triangulation is a triangle net in which every triangle satisfies the Delaunay condition: the circumcircle of each triangle includes only the vertices of the triangle. In other words, the circumcircle does not contain any vertex of other triangles (van Kreveld 2014). Constrained edges in a Delaunay Triangulation have been used as fixed edges into the triangulation. Constrained Delaunay Triangulation (CDT) and Delaunay Constrained Triangulation (DCT) are extensions of Delaunay Triangulation including constraints widely studied. The Fig. 1 represents a Delaunay Triangulation and the Figs. 2 and 3 depicts a CDT and a DCT, respectively.



Constrained Edges and Delaunay Triangulation, Fig. 1 Delaunay Triangulation



Constrained Edges and Delaunay Triangulation, Fig. 2 Constrained Delaunay Triangulation



Constrained Edges and Delaunay Triangulation, Fig. 3 Delaunay Constrained Triangulation

Introduction

An algorithm with optimal time to compute CDT was firstly proposed by Chew (1987), whereas Rognant et al. (1999) defined for the process of inserting constraints into a Delaunay Triangulation two different methods: stable and unstable. Stable methods begin with a Delaunay Triangulation, inserts a constrained edge, and produces another Delaunay Triangulation. Contrarily, an unstable method does not produce a Delaunay

Triangulation, for instance, CDT is an unstable method. Some CDT algorithms were documented by Agarwal et al. (2005); Shewchuk and Brown (2015).

Constrained Delaunay Triangulation

Given a set of n_1 vertices $V(n_1)$ and a set of m constrained edges $E(m)$, whose endpoints are $V(n_2)$, a CDT is a net of nonoverlapping triangles whose set of vertices is $V(n) = V(n_1)\ U\ V(n_2)$, all constrained edges $E(m)$ are included as edges of the triangulation and it is as Delaunay as possible. ($V(n_1)$ may be Ø.) The strong lines in the Fig. 2 represent the constrained edges.

Delaunay Constrained Triangulation

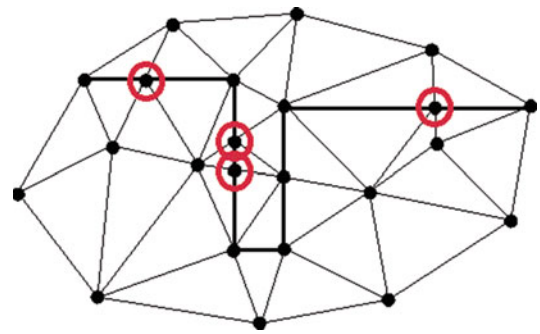
Given a set of n_1 vertices $V(n_1)$ and a set of m constrained edges $E(m)$, whose endpoints are $V(n_2)$, a DCT is a net of nonoverlapping triangles whose set of vertices is $V(n) = V(n_1)\ U\ V(n_2)\ U\ V(n_3)$, where $V(n_3)$ is a set of n_3 virtual vertices, all constrained edges $E(m)$ are included as edges of the triangulation, and it is a Delaunay Triangulation. ($V(n_1)$ and $V(n_3)$ may be empty.) Only the strong red lines are included in a DCT as constrained edges, then the strong black lines are ignored.

Delaunay Triangulation can use fixed edges, which are usually called constrained edges or briefly constraints. Delaunay Triangulation must be called CDT (for more details, see Chew (1987); van Kreveld (2014)). In a CDT, the priority is the constrained edges; it means, the triangulation must include the constrained edges. In other words, the most important is preserve constrained edges rather than the Delaunay structure. Consequently, the result is a triangulation including all the constrained edges even though some triangles do not pass the Delaunay condition (Chew 1987). In contrast, for DCT the most important is to conserve the Delaunay nature rather than guarantee the constrained edges (Rognant et al. 1999; Dinas and Bañón 2012). Thus, the result is a Delaunay Triangulation with as many as possible constrained edges (some constrained edges can be ignored or excluded of the final triangulation). However, there are a several ways to preserve the constrained edges and the Delaunay structure, but it requires virtual vertices. In the Fig. 4, the virtual vertices are enclosed in red circles.

Constrained Delaunay Triangulation

CDT were introduced independently as Generalized Delaunay Triangulation (Lee and Lin 1986) and as Obstacle Triangulation by Chew (1987). Restricted Delaunay Triangulation was the name used for others (Anglada 1997). A triangle is Constrained Delaunay if its interior does not intersect any input segment, and its circumcircle does not enclose vertices visible from the interior of the triangle. Nevertheless, an edge is Constrained Delaunay if it does not cross any input segment, and it has a circumcircle which does not enclose vertices visible from the interior of the edge.

Several authors have worked on CDT; for instance, Agarwal et al. (2005) worked on the efficiency for input-output data based on the construction process to optimize the use of the memory. Shewchuk (2008) explored the weighted Constrained Delaunay Tetrahedralizations whereas Dinas and Bañón (2012) proposed to take data from images; the construction of Delaunay Triangulation uses a cloud of points from images and a set of edges E captured from images are the constrained edges for Constrained Delaunay Triangulations. Dinas and Martínez (2019) worked on the constrained edges and Kinetic Delaunay Triangulation as a collision detection approach. In contrast, Domiter and Zalik (2008) worked on accelerating the location process for inserting new vertices, whereas Nam et al. (2009) worked on accelerating the algorithm and Eder et al. (2018) worked on the parallelization of the polygons with holes in



Constrained Edges and Delaunay Triangulation, Fig. 4 Delaunay Constrained Triangulation and virtual vertices

Constrained Delaunay. Additionally, refinement methods have been used to improve CDT Algorithms (Engwirda and Ivers 2015).

Constrained Delaunay Triangulation Algorithms (CDT)

The input is a set of constrained edges usually called a Planar Straight-Line Graph (PSLG) and the set of vertices of the triangulation. The output is a CDT where every edge is locally Delaunay except for constrained edges.

Incremental Construction

Anglada's algorithm (Anglada 1997) starts with a Delaunay Triangulation that is constructed using the set of vertices $V(n)$, and then localizes the constrained edge in the triangulation.

Incremental Insertion

Based on Anglada's algorithm (Anglada 1997), the proposal of Nam et al. (2009) accelerates the point location by using Skvortsov's algorithm and a uniform grid.

Randomized Incremental Construction

A randomized implementation based on Anglada's algorithm (Anglada 1997) was proposed by Agarwal et al. (2005). This approach includes in the Delaunay Triangulation the endpoints of the constrained edges, it means, the endpoints of the constrained edges are used to construct the Delaunay Triangulation.

Randomized Incremental Segment Insertions

Typical implementations for segment insertion take $O(kn^2)$, where n is the number of input vertices and k is the number of input segments. Inserting a constrained edge into a CDT takes $O(n \log n + n \log^2 k)$ (Agarwal et al. 2005). This algorithm deletes the edges intercepted by the constrained edge, inserts the constrained edge in the cavity, and retriangulates it. An improved algorithm proposed by Shewchuk and Brown (2015) decreases the complexity to $O(n \log^2 k)$ by computing the segment location procedure before the segment insertion procedure. Finally, the Shewchuk and Brown (2015) is close related to the Chew's implementation of deleting a vertex in linear time.

Divide and Conquer

Chew (1987) proposed a divide and conquer algorithm for CDT. The set of vertices $V(n)$ is divided into vertical rectangles, which contains exactly one vertex. Additionally, there are crossing lines inside the rectangle that represent the constrained edges. Thus, the triangulation is constructed by using the crossing lines and the constrained edges. Finally, the strips are merged to complete the CDT; it takes $O(n \log n)$ time (Chew 1987).

Plane Sweep

Domiter and Zalik (2008) proposed an algorithm focused on the main bottleneck of the algorithm: locating the triangle in which a new vertex falls; thus, the cost of inserting an edge into a CDT decreases. The worst time complexity of the proposed algorithm was $O(n^2)$.

Delaunay Constrained Triangulation (DCT)

DCT produces stable method because the final triangulation guarantees the Delaunay structure and respects constrained edges, at the same time. Stable methods can be constructed by inserting new vertices in the triangulation referred as Virtual Vertices. It is also known as Conforming Delaunay Triangulation; its edges are all locally Delaunay. As DCT is a Delaunay Triangulation, the construction time is related to the Delaunay time, but the number of virtual vertices depends on the selected method. Additionally, Shewchuk (2008) reported Conforming Delaunay Triangulation. The proposed algorithms accept in the input small angles, and then new vertices are included to increase the quality by eliminating small angles. In the worst case, the input needs!(n^2) to $O(n^{2.5})$.

Rognant et al. (1999) defined stable and unstable methods according to the result: they are stable if they produce a Delaunay Triangulation.

Virtual Vertices

A virtual vertex is a vertex, which does not belong to the initial set of vertices $V(n)$ of the triangulation; it is created to divide constrained edges into smaller pieces with the purpose of creating a DCT. Several authors have been working on inserting vertices to the triangulations by different methods; for instance, the Steiner Points by Engwirda and Ivers (2015). Virtual vertices use the constrained edges; nevertheless, its creation or selection depends on the applications. For instance, virtual vertices can be created by the intersection between a pair of constrained edges or between a constrained edge and a Delaunay edge. According to the kind of intersection, it can be classified into three groups: (i) An X intersection, it is necessary to divide two constrained edges into four new constrained edges, where each constrained edge has a unique vertex and one virtual vertex. (ii) A T intersection, it happens when an endpoint of a constrained edge is involved in the intersection. It requires to split only one edge into two edges, but it is not required to create a new virtual vertex, and (iii) an L intersection, which does not require virtual vertices.

Delaunay Constrained Triangulation Methods

In this section, the set of methods that can be used to construct a DCT is explained.

Constrained Delaunay Triangulation

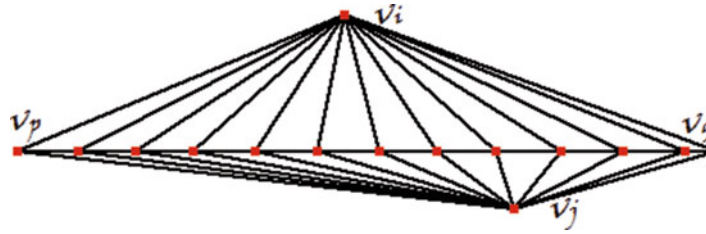
CDT respects constrained edges, and the resulting triangulation is as close as possible to a Delaunay Triangulation; it means, there is not guaranteed that the resulting triangulation is a Delaunay Triangulation. An advantage of this triangulation is that their construction does not require additional vertices and the disadvantage of this triangulation is that it is not always a Delaunay Triangulation. To guarantee both, the constrained edges and the Delaunay Triangulation, it is possible to convert a CDT into a DCT by inserting new vertices inside the triangulation. In the next sections are briefly documented the following methods: densification, dichotomy, orthogonal projection, intersection, bisection, and trisection methods.

Densification

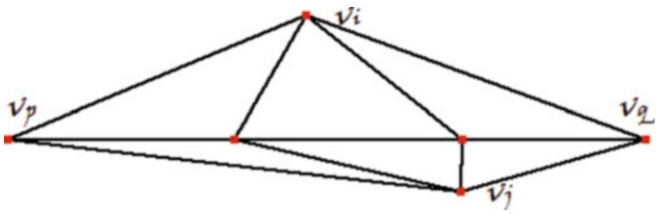
Densification method is constructed by a set of steps that should be applied to each constrained edge inside the triangulation (see Fig. 5). The first step is to find in the set of vertices $V(n)$ the nearest vertex to the constrained edge. After, to calculate the length d from this vertex to the constrained edge; d is used to divide the constrained edge into m small constrained edges with length of at least d. That is to say, at least m – 1 of the m new small constraints have size d (Faugeras et al. 1990); however, it can be modified to include m segments with equal length. This method can produce a big number of virtual vertices; however, the main advantage of this method is that it does not require the inCircle test for the new the triangles.

Dichotomy

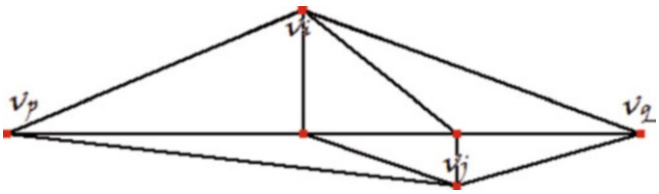
A DCT is created by dividing each constrained edge into small constrained edges; the size of each segment can be defined by the author or can be randomly selected, as is shown in Fig. 6. The densification method guarantees the existence of the right set of virtual vertices of the dichotomy method. Compared to the densification method, it



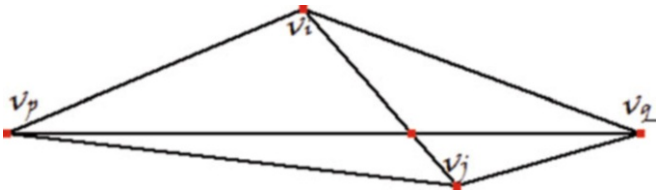
Constrained Edges and Delaunay Triangulation, Fig. 5 Densification method for Delaunay Constrained Triangulation



Constrained Edges and Delaunay Triangulation, Fig. 6 Dichotomy method for Delaunay Constrained Triangulation



Constrained Edges and Delaunay Triangulation, Fig. 7 Orthogonal projection method for Delaunay Constrained Triangulation



Constrained Edges and Delaunay Triangulation, Fig. 8 Intersection method for Delaunay Constrained Triangulation

is equally reliable; it is computationally less expensive and requires less additional vertices. The advantage of this method is that it defines the constrained edge partition as simple as possible and it does not produce more virtual vertices than necessary for the triangulation to be Delaunay; the disadvantage is that it requires the inCircle test for the new triangles. Rognant et al. (1999) reported a brief explanation.

Orthogonal Projection

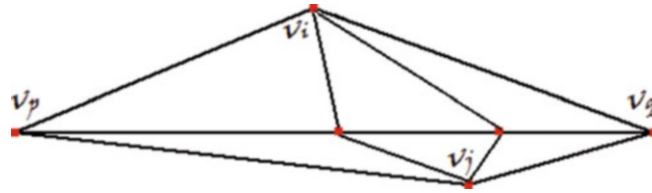
In Fig. 7, the orthogonal method is done for each vertex located around a constrained edge. Each of these vertices is orthogonally projected on the constrained edge; consequently, it produces an edge that is orthogonal to the constrained edge. Thus, each virtual vertex is the orthogonal projection of the vertex on the constrained edge. This method is reliable; the orthogonal projection is not a complex procedure; additionally, the number of new virtual vertices depends on the number of vertices that are around to the constrained edge (Rognant et al. 1999). The shortcoming of this method is that the cost of calculating the virtual vertices is computationally high.

Intersection

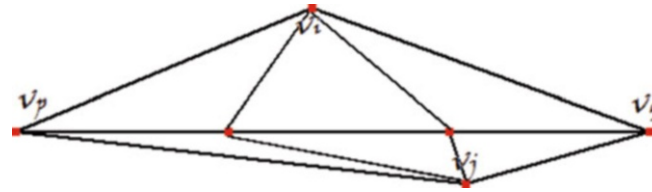
The result of overlapping a Delaunay Triangulation and be constrained edges is shown in Fig. 8; the intersection between the constrained edges create the virtual vertices. This method can be used to insert constrained edges into a Delaunay Triangulation. When the Delaunay Triangulation is unknown, constructing it can be more expensive than using another method; however, it is reliable. A fast way to create the intersection vertices is to find a pair of vertices on opposite sides that surround the constrained edge, and then calculate the intersection vertex between the constrained edge and the segment formed by the pairs of vertices surrounding the constrained edge. Finally, complete the triangulation by connecting the virtual vertices with the surrounding vertices (Rognant et al. 1999). This approach is based on the Anglada's algorithm to insert segments in a CDT (Anglada 1997).

Bisection

Bisection method is based on a divide and conquer approach depicted in Fig. 9: it is simple to implement, and the inCircle test must verify the result. The first step is to bisect the constrained edge and



Constrained Edges and Delaunay Triangulation, Fig. 9 Bisection method for Delaunay Constrained Triangulation



Constrained Edges and Delaunay Triangulation, Fig. 10 Trisection method for Delaunay Constrained Triangulation

locate a virtual vertex. Then connect the virtual vertex with the set of vertices surrounding the constrained edge. Finally, evaluate the triangles by the inCircle test, if any triangle does not satisfy the circumcircle condition, then bisect the piece of the constrained edge again until each triangle satisfies the circumcircle condition. The advantage of this method is that it defines a simple constrained edge partition and it does not produce more virtual vertices than necessary for the triangulation to be Delaunay. The shortcoming of this method is the necessity of evaluating the result after each division. Other methods as densification and intersection methods produce correct DCT and do not require evaluation; however, their procedure to locate the virtual vertices is not as straightforward as the used for bisection method.

Trisection

This method is based on a divide and conquer approach (see Fig. 10) it is simple to implement, and the inCircle test must verify the result. The first step is to trisect the constrained edge and locate two virtual vertices. Then connect the virtual vertices with the set of vertices surrounding the constrained edge. Finally, evaluate the triangles by the inCircle test, if any triangle does not satisfy the circumcircle condition, then trisect the piece of the constrained edge again until each triangle satisfies the circumcircle condition. The advantage of this method is that it defines a simple constrained edge partition and it does not produce more virtual vertices than necessary for the triangulation to be Delaunay. The shortcoming of this method is the necessity of evaluating the result after each division. Other methods as densification and intersection methods produce correct DCT and do not require evaluation; however, their procedure to locate the virtual vertices is not as straightforward as the used for bisection method. The number of virtual vertices produced by the bisection and trisection are expected to have similar behavior, even though the bisection method requires more levels of partition, but the trisection method produces more virtual vertices per partition.

Conclusion and Discussion

Delaunay Constrained Triangulation and Constrained Delaunay Triangulation have remarkable difference between them. Both triangulations can be used to represent constrained edges in a triangulation; however, the use depends on the purpose. While CDT is flexible with Delaunay Triangulation, it is much stricter with constrained edges. In contrast, DCT is flexible with constrained edges but stricter with a result that passes the conditions of Delaunay Triangulation. The inclusion of artificial vertices called virtual vertices can help to guarantee both: the Delaunay structure and de constrained edges. Finally, reviewed methods are based on virtual vertices: densification, orthogonal projection, dichotomy, and intersection, and the proposed methods: bisection and trisection.

Cross-References

- ▶ Delaunay Triangulation
- ▶ Modeling and Mesh Processing for Games
- ▶ Teaching Computer Graphics by Application
- ▶ UV Map Generation on Triangular Mesh

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Constructing Game Agents Through Simulated Evolution

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Synonyms

Evolutionary agent design; Evolutionary algorithms; Evolutionary computation; Evolutionary machine learning; Neuroevolution

Definition

Construction of game agents though simulated evolution is the use of algorithms that model the biological of process of evolution to develop the behavior and/or morphology of game agents.

Introduction

Computer game worlds are often inhabited by numerous artificial agents, which may be helpful, neutral, or hostile toward the player or players. Common approaches for defining the behavior of

such agents include rule-based scripts and finite state machines (Buckland 2005). However, agent behavior can also be generated automatically using evolutionary computation (EC; Eiben and Smith 2003). EC is a machine-learning technique that can be applied to sequential decision-making problems with large and partially observable state spaces, like video games.

EC can create individual agents or teams, and these agents can be opponents or companions of human players. Agents can also be evolved to play games as a human would, in order to test the efficacy of EC techniques. EC can even create game artifacts besides agents, such as weapons. The reason EC is so flexible is that it requires little domain knowledge compared to traditional approaches. It is also capable of discovering surprising and effective behavior that a human expert would not think to program. If applied intelligently, this approach can even adapt to humans in a manner that keeps providing interesting and novel experiences for players. This article focuses mostly on discovering effective opponent behavior (since that is the focus of most research), although examples of other applications are also given when appropriate.

Evolutionary Computation

EC models the process of Darwinian evolution by natural selection (Darwin 1859) for the purpose of generating solutions to difficult embedded problems. Initially, a random collection of candidate solutions, called the population, is generated and evaluated in a task within some environment. Because of randomness in how the population was generated, there will be variation in the performance of different candidate solutions. At this point a new population is generated from the old population using a mixture of selection, recombination, and mutation.

Selection is based on Darwin's concept of natural selection, by which fitter individuals enjoy higher reproductive success. It involves identifying members of the population that perform best, typically through a fitness function that maps candidate solutions to numeric measures of performance. Sometimes a certain number of top performers are selected directly (a technique known as elitism), but selection is generally a random process that merely favors high-performing individuals, while still allowing some poor-performing, but lucky, individuals to be chosen. This random element is one way of maintaining diversity in the evolving population and is generally important to the long-term success of evolution.

In order for evolution to progress, some of the slots in the new population must be filled by results of recombination or mutation. Recombination creates a new solution to the problem by combining components of solutions that were selected from the old population. Generally, two solutions from the old population, called parents, are selected and recombined to create a new solution, a child or offspring, via simulated crossover, which models the process of genetic crossover that is a major benefit in biological sexual reproduction. In addition, some of these offspring undergo mutation before joining the new population.

Mutation operations are applied with low probability and generally result in small changes to a candidate solution. It is also possible, and common, for mutation to be applied directly to members of the old population to generate new solutions, which can also fill slots in the new population. Mutation without recombination models asexual reproduction.

The new population of candidate solutions is labelled the next generation of the evolutionary process. The new population now also undergoes evaluation and is subject to selection, recombination, and mutation, which leads to yet another generation, and so on. Because recombination and mutation keep creating new individuals, this process is able to search the space of possible solutions in parallel, and because selection favors high-performing individuals, this search will gradually focus on the best solutions in the search space. As such, the evolutionary process is repeated until some stopping criteria is reached, such as the attainment of a desired level of performance, or the end of a preset number of generations.

A major benefit of this process is that it is general: it can be applied to any domain in which there is a measure of fitness/performance that allows certain solutions to be identified as being better than others.

Evolution in Games

Games are typically full of numeric scores and metrics that can easily be used as a means of measuring agent performance. Each possible agent is a candidate solution to the problem of how to behave in the game world. Several different representations for such agents are discussed later, but even given such a representation, there are different ways of evaluating an agent's performance.

Although most game agents are ultimately designed to interact with humans, having humans evaluate all candidate solutions is seldom feasible because it is difficult for humans to maintain focus and evaluate solutions consistently. Completely automated approaches are more commonly used, but sometimes humans can also be incorporated into the process.

Evolution in Stationary Worlds

A simple approach to evolving agent behavior is to have an evolved agent interact only with a static or stationary world. Such worlds may have no other agents in them or may only have agents with fixed control policies. A world is stationary if it and its agents do not adjust or adapt to what occurs during evaluation. In other words, the probability of experiencing certain outcomes in certain situations remains the same.

An example of an agent evolving in a stationary world without other agents is a racecar controller on a track without other cars. This process can produce skilled racing behavior (Cardamone et al. 2009). To add to this agent the ability to interact with other racecars, a scripted component could be added to the controller that takes over when other cars are near, thus combining scripted and evolved components. Another option is to evolve a racecar controller in an environment filled with scripted opponent cars. A variety of different scripted opponents could be used, either in one trial or across the course of several, in order to make the discovered behavior more robust in the face of different opponents.

Scripted controllers could be rudimentary yet still pose an interesting challenge for an evolved controller to overcome. However, scripted opponents may have weaknesses that evolution can discover and exploit. Such behaviors may result in a high score, even though they may be uninteresting or easily defeatable for human players. Fortunately, the evolutionary approach can be generalized and extended into a process that discovers good behaviors in an absolute sense. This process is coevolution.

Coevolution

Coevolution occurs when individuals in a population are evaluated with respect to other evolved individuals. Such individuals can come from the same or different populations and can be evaluated in tasks requiring cooperation or competition. A prominent example of competitive coevolution within a single population is Fogel's (2002) evolved checkers player, Blondie24. Blondie24 was evolved by an evolutionary algorithm that pitted evolved players from a single population against each other. The players that did a better job of defeating other members of the same population had higher fitness and were used to create more offspring for the next generation. The best individual after many generations used the name Blondie24 on an online checkers service and was found to be highly competitive against the human players it faced.

Although checkers is a traditional board game, the same coevolutionary process can be used in video games where bots are needed to fill in for human players. First-person shooter (FPS) games, like the Unreal Tournament and Quake franchises, fit this model because during the deathmatch mode of play (a free-for-all competition between agents trying to kill each other for points), all agents in the game have the same in-game representation and available action set, making it straightforward to evolve such agents with a single homogeneous population.

When the representations and available actions of different classes of agents are different from each other, it makes more sense to evolve separate populations for each type of agent and define their fitnesses in relation to each other. For example, fighting games, like the Street Fighter and Tekken franchises, pit two characters against each other in direct one-on-one competition and generally feature a variety of characters. Therefore, the abilities of the two players may be completely different from each other.

For example, assume that the goal of coevolution is to discover skilled controllers for Ryu and Guile in Street Fighter (at least, each controller will become skilled with respect to its particular opponent). In this scenario, there is a population of Ryu controllers and a population of Guile controllers: each evaluation is a match between a member of each population in which performance depends on the amounts of damage dealt and received by each controller (there are various ways to evaluate performance with respect to these two scores). Any improvement in the performance of individual Ryu controllers will come at the expense of Guile controllers, because the two populations are in direct competition. When set up correctly, this process will result in an evolutionary arms race, encouraging each population to find new ways to overcome the other.

However, there are many potential pitfalls to this process. For example, because each member of each population is different, evaluations of the Ryu population will not be consistent if each Ryu controller faces a different member of the Guile population. There is a risk of a mediocre Ryu controller receiving a high performance rating simply because it was paired with a poor Guile controller. This problem can be somewhat mitigated if every member of each population faces off against several members of the other population, and overall performance depends on performance in all evaluations. However, performance will only be completely consistent if the set of opponents for each population is the same, and picking an appropriate set of opponents is challenging.

Unfortunately, if the set of opponents is chosen poorly, the two populations will not improve in an absolute sense. Instead, they may simply get better with respect to each other in ways that a human player will find bizarre or incompetent. Such improvements may go through alternating cycles because they lead to behavior that beats the current prevalent opponent behavior but has a weakness against another easily discovered opponent behavior. The trick with coevolution is to discover behavior that incorporates all of the strengths while avoiding all of the weaknesses available within the population's range of possible behaviors.

In some domains, performance that is good in an absolute sense will be achieved automatically. In others, it may be necessary to keep evaluating each population against an archive of defeated opponents to assure that agents never lose the ability to overcome opponents their ancestors could defeat.

Although coevolution can give rise to behavior that is intelligent in an absolute sense, it is hard to implement correctly. However, agent behavior only needs to be interesting with respect to human players, and there are also ways to evolve agent behavior by including humans in the loop.

Evolving with Humans in the Loop

As mentioned before, the main challenges to evolving against humans are that they have a limited ability to maintain focus for long periods of time and that they are not consistent in their evaluations.

A computer can usually run many evaluations between computer opponents very quickly, but all evaluations with a human must occur in real time. After many such evaluations, a human is likely to become fatigued and be unwilling to expend the necessary effort to evaluate agents properly. Naturally, this tendency also makes evaluations inconsistent. However, fatigue is less likely to occur if it is possible to evaluate many agents at once, or if the population is sufficiently small. Fatigue can also be avoided if a prolonged evaluation process is simply the point of the game.

For example, the commercial Creatures (Grand et al. 1997) series of games is centered around raising artificial creatures called Norns. Superficially, the game looks like a virtual pet-style

game, but among many other AI techniques applied in the game is support for evolution. The creatures the player raises grow, mature, and seek mates. The Creatures games take place in open-ended worlds in which the fun comes from nurturing and interacting with Norns. However, these lengthy interactions influence when and with whom each Norn mates and therefore influence the direction evolution takes in the creation of new Norns.

The model used in the Creatures games is interesting and unique, but too slow and time intensive to be useful in most other genres. Inconsistency in human evaluations is also not terribly relevant in the Creatures games because variation and novelty in the results of evolution are part of the fun of the game. Additionally, there is no set goal that the evolved Norns are supposed to achieve, but the game is entertaining precisely because of the variety it produces.

Another manner in which a human may be an inconsistent evaluator is due to a human's tendency to learn and adapt: a human player that changes strategy mid-generation will evaluate members of the same generation differently, which would likely give an advantage to agents evaluated before the human adopted a new strategy.

However, human adaptation is also a potential benefit. Inconsistent evaluations may add noise to the evolutionary process, but in the long run a human or set of humans who evaluate artificial agents will settle on strategies that suit their computer opponents. However, if the humans adapt and improve, then the evolved agents should improve as well. In fact, if this improvement happens in real time, then the resulting experience is more exciting and engaging for the human player.

Therefore, the primary challenge to evolving agents with humans in the loop is in generating new and interesting behaviors quickly enough to keep humans engaged. In general, having one human be responsible for evaluating all individuals puts an unreasonable burden on that individual, so methods that keep humans in the loop need to distribute evaluations in novel ways. These evaluations can either be distributed among several different humans or split between humans and the computer.

Sharing evaluations with the computer means that the computer still evaluates the majority of candidate solutions in the usual way, using a computer-controlled opponent as a stand-in for a human player. This process could in fact be carried out for many generations, only occasionally letting a human face the best evolved agents. If performance against the human is comparable to performance against the computer-controlled stand-in, then evolution is on the right track. Otherwise, data on how the human plays can be collected and used to adjust the behavior of the stand-in. These adjustments can be made using supervised learning techniques, or by evolving the stand-in to emulate human play better. However, such a system is complex, and a great deal of effort is required to make sure all of the separate components successfully interact.

A conceptually simpler way to distribute evaluations is across many human players. Although using different human players makes inconsistencies in evaluation even more likely, there will at least not be any systematic tendency toward generating behaviors that are inappropriate for human consumption: if any human can exploit an agent's failings, then it will eventually be weeded out of the population. Furthermore, distributing evaluations across many humans is made easier by the Internet: specifically, tools such as Amazon's Mechanical Turk and massively multiplayer online (MMO) games.

In fact, although the MMO model has not yet been used to evolve agent behaviors specifically, EC has succeeded in the MMO video game Galactic Arms Race (Hastings et al. 2009). This space-based action shooter game evolves diverse weapons for users to find and equip on their spaceships. The weapon preferences of all users determine the fitness of weapons. The most popular weapons are more likely to create offspring, i.e., new weapons that players are given when they defeat certain enemies. A similar model could apply for enemy agents in many MMO worlds, with enemies that are more successful in combat with human players being considered more fit,

and giving rise to increasingly challenging offspring. Such a process has the potential to give rise to new types of games in which all agents evolve and adapt based on a community of human players.

Evolving Humanlike Behavior

Pitting evolved agents against human opponents will assure that incompetent behaviors are weeded out of the population. However, simply discovering skilled behavior is not always a problem. Because artificial agents are differently embodied than human-controlled avatars, they may have unfair access to skills that are difficult for humans to develop, which in some cases means that they quickly become too skilled to be good opponents for humans. For example, in Unreal Tournament 2004, artificial agents can be programmed using a system called Pogamut (Gemrot et al. 2009). It is easy for these agents to shoot their weapons with pinpoint accuracy: evolution thus creates skilled agents, albeit in a way that human players find frustrating and inhuman.

However, evolution can still be applied in these situations. Agents can be evolved to maximize performance, but under restrictions similar to those experienced by humans. The ability of such an agent to behave in a humanlike manner was demonstrated in the 2007–2012 BotPrize competition. The purpose of the competition was to develop bots for Unreal Tournament 2004 that human players would mistake for humans at least 50 % of the time. The bot UT^2 achieved this goal with evolved combat behavior (Schrum et al. 2012). The key idea was to optimize the behavior under humanlike restrictions: the more quickly it was moving and the farther its targets were, the less accurate it was. These restrictions forced the bot to evolve humanlike movement patterns in order to have skilled behavior.

This example demonstrates how the abilities available to an evolved agent have a strong influence on the range of behaviors that are likely to be evolved. These abilities are in turn influenced by the type of controller evolved for the agent. A variety of controllers that can be evolved to produce game agents are discussed next.

Evolved Representations

When constructing agents for games via evolution, each candidate solution is a means of representing an agent. Often, this representation needs only account for the behavior of the agent, because its form is often fixed by the constraints of the game. However, diverse agent morphology can also be evolved. Regardless, there are a variety of representations that can be used to suit the needs of any particular game.

Parameter Tuning

The simplest way to incorporate evolution into traditional agent design is via parameter tuning. If there is an existing controller for an agent whose behavior is influenced by some key parameters, then these parameters can be optimized using evolution (typically via genetic algorithms or evolution strategies).

For example, a hand-coded controller for an agent in an FPS may have numeric parameters indicating which weapon to favor, depending on the agent's distance from its opponents. Similarly, such an agent may have several distinct control modules, like *attack*, *retreat*, and *explore*, and might decide which one to use based on numeric features such as its own health and its distance from enemies and items. Evolved parameters then specify the exact thresholds for each feature, indicating when one module is used instead of another.

The strength of parameter tuning depends on the strength of the underlying controller. For a bad controller, no amount of parameter tuning may be able to help. Similarly, a very good controller may not be very difficult to tune, resulting in quick but small improvements in performance. In order for evolution to reach its full potential, the evolved representation needs to exist within a search space that is rich enough to contain skilled solutions that a human designer either would not consider, or would have difficulty creating.

Rule-Based Scripts

Rule-based scripts are a common approach to specifying the behaviors of agents in commercial games. Typically, considerable effort and person-

hours go into designing scripts for each agent in the game. Simple agents can have simple scripts, but scripts for opponents must be complicated in order for the game to be challenging and interesting.

Scripts generally consist of a list of rules, and each rule consists of a trigger and a corresponding action or sequence of actions. Triggers and actions may also be parameterized. Evolution can easily rearrange blocks of information and search the parameter spaces of each rule and trigger. Of course, the process can be difficult if there is a large number of basic triggers and actions.

One game genre in which opponents have a large range of possible actions is real-time strategy (RTS) games. Because the computer opponent must control a collection of agents in a large space, the number of actions available is massive. Therefore, it makes more sense to reason about behavior at a higher level. Given a set of high-level actions, or tactics, to choose from, a reinforcement learning technique called dynamic scripting can be used to select the best tactic for each situation, leading to improved behavior. In its basic form, this technique is still limited by the preprogrammed tactics available to the agent. However, dynamic scripting can be combined with evolution that generates new tactics. This process has been successfully applied to Wargus, a clone of the very popular Warcraft II RTS game (Ponsen et al. 2006).

Since commercial game designers are already comfortable using scripts, evolving scripts is a straightforward way to combine existing industry knowledge with cutting-edge AI techniques. However, there are also evolvable representations that are potentially more powerful, but less well known in the game industry.

Genetic Programming

Genetic programming (GP) is a technique for evolving computer programs, or more accurately subroutines, that are often represented as trees. Each internal node is a function call whose branches are input parameters, and leaves are either constants, or functions with no parameters. These functions with no parameters provide sensor values from the agent to the program.

For any given game, the specific functions that can be used in evolved trees need to be specified by the programmer. The types of functions used depend on how the evolved trees are used to control an agent. Evolved trees could be straightforward function approximators made up of purely mathematical functions using agent sensors to provide numbers. However, trees with arbitrarily complex functions can also be evolved. For example, functions can have side effects that directly lead to agent action or that alter a stored memory structure whose contents can influence future function evaluations.

GP can also be used to evolve behavior trees. Such trees hierarchically decompose behavior into a collection of tasks that are prioritized and then executed only if certain triggers are satisfied. In fact, a behavior tree can be thought of as a hierarchical rule-based script. Behavior trees were initially developed for the commercial release of Halo 2 (Isla 2005) and have since been evolved in Unreal Tournament 2004 using Pogamut (Kadlec 2008).

GP can also be used as part of a developmental process: the evolved programs are executed to create some other structure that is actually used to control the agent. Such a process more closely emulates the creation of complex organisms from DNA. With GP, an evolved program tree can be used to create the structure and weights of a neural network (Gruau et al. 1996) or simply be queried to fill in the weights of a predefined network architecture (Togelius et al. 2009). Neural networks have their own set of advantages as agent control mechanisms, which are discussed next.

Neuroevolution

The human brain is a neural network made up of neurons that connect to each other via synapses and communicate via electrical signals. An artificial neural network is an abstraction of this idea that transmits numerical values in place of electrical signals, and neuroevolution is the process by which artificial neural networks are evolved to solve problems.

There are many neural network models (Haykin 1999), but the most common is a multilayer perceptron (MLP), consisting of input

neurons, output neurons, and hidden neurons in between. Each neuron is connected to every neuron in the next layer, and a continuous activation function, typically a sigmoid, transforms the numerical signals accumulated in each neuron. MLPs are universal function approximators, assuming the correct number of neurons/layers is available, so they are useful in defining agent behavior. MLPs can be trained by supervised learning if labelled training data is available, but this is seldom the case when defining agent behavior in games.

MLPs typically have their architecture (number of neurons in each layer) fixed before learning, and in such a setting there is a known number of synaptic weights in the network. Discovering the weights for such networks is therefore a special case of parameter tuning. Although intelligent behavior can be learned using MLPs, the large number of parameters can make it difficult to learn particularly large MLPs.

An alternative approach is NeuroEvolution of Augmenting Topologies (NEAT; Stanley and Miikkulainen 2002), which does not produce MLPs. Rather, NEAT networks can have neurons connected to each other in an arbitrary topology. All networks start evolution with a minimal topology with no hidden neurons. The networks in the population gradually complexify across generations as new neurons and links are added via mutations, which allows for convoluted, but effective topologies. In fact, by beginning the search in a small space with few links, it is often possible to find very effective simple networks with fewer links than an MLP with the same number of inputs and outputs.

A variant of NEAT that allows a team of agents to learn in real time (rtNEAT; Stanley et al. 2005) was actually the driving force behind a machine-learning game called Neuro-Evolving Robotic Operatives (NERO), in which the player takes on the role of a virtual drill sergeant to train robot soldiers that learn via neuroevolution. NEAT has since then been applied to many other video games.

An extension to NEAT called HyperNEAT (Stanley et al. 2009) can exploit the geometry of a state space to make learning certain behaviors easier. HyperNEAT networks are evolved with NEAT, but with extra activation functions possible in the neurons to capture symmetries and repeated patterns in the domain. Most importantly, each evolved network is used to create another network, which becomes the actual controller of an agent. This is another example of a developmental process (cf. section "Genetic Programming"). A benefit of this process is that it becomes feasible to generate very large, but effective, controller networks from small evolved networks. In fact, HyperNEAT has been effectively applied to simulated RoboCup Soccer Keepaway (Verbancsics and Stanley 2010) and general game playing of Atari games (Hausknecht et al. 2012) using controller networks whose input layers were linked to 2D grids spanning the entire visual display. Such massive networks are difficult to evolve when each connection weight must be learned individually.

HyperNEAT is known to produce regular networks with repeating patterns. However, these networks are not inherently modular (though techniques to encourage such modularity exist; Huizinga et al. 2014). Modularity is useful because a challenging problem can be broken down into smaller components that are easier to learn. Breaking up a controller into several distinct subcontrollers is a useful way to achieve multimodal behavior, i.e., behavior that consists of distinct modes subjectively different from each other. Such behavior is necessary in many games, because different strategies often require different actions, such as attacking, retreating, searching, hiding, etc.

Such multimodal behavior can be discovered with neuroevolution through architectures that support multiple distinct output modules. Such modules can exist in the initial population or be added by a mutation operator called module mutation (Schrum and Miikkulainen 2014). This technique was applied to Ms. Pac-Man, and the evolved networks discovered both expected modes of behavior – such as a mode for fleeing threat ghosts and a mode for chasing edible ghosts – and unexpected modes of behavior, such as one for dodging ghosts after luring them

near a power pill, so that when the ghosts became edible they would be easier to eat.

So far, only means of evolving complex controllers have been discussed. However, it is possible to go beyond evolving controllers and evolve the bodies of agents as well.

Morphology

EC can be used to create many types of structures beside function approximators. The Evolved Virtual Creatures (EVCs; Sims 1994; Lessin et al. 2014) community has developed ways of evolving interesting creature morphologies, often using graph-based encodings. These encodings allow for arbitrary numbers of limbs and joints arranged in novel ways. Sometimes these morphologies mimic those of real-world organisms, but more unusual morphologies can also emerge; the strange quality of such morphologies would lend itself well to a game filled with aliens, robots, or other bizarre creatures.

Given the body, a means of controlling it is required. Specifically, engaging and disengaging the existing joints and/or artificial muscles will cause parts of the body to move, which can lead to complex behavior if done properly. Sometimes simple repetitive control signals, as from a sine wave, can lead to interesting behavior given the right morphology. Naturally, a human designer could also step in and provide the behavior for an evolved morphology.

However, EVCs can also have their control routines embedded into their morphologies. In particular, specific sensors situated on an EVC can be linked to its muscles and joints. Internally, these connections can be wired in a manner similar to a neural network or electrical circuit, meaning that sensor values may be aggregated and/or serve as inputs to functions, whose outputs are passed on until they eventually determine muscle and joint behavior. Such controllers have been evolved to run, jump, swim, grab objects, chase after a light source, and fight or flee different opponents. These skills could serve as the building blocks for more complex and interesting game agents.

Conclusion

Evolutionary computation is a powerful machine-learning technique that has been used to discover skilled and interesting agent behavior in many domains. Video game agents can be evolved to play the game as a human would, to serve as opponents for human players, or can be evolved in a context where interacting with the evolutionary process is the point of the game.

Despite the ability of evolution to discover diverse and interesting agent behaviors, the commercial games industry has not yet harnessed the power of evolution (and other advanced AI techniques). This article provides a useful starting point for understanding what can be done with evolution in games and also points out some areas of untapped potential.

Cross-References

▶ Machine Learning

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Construction Management Processes in a Digital Built Environment, Modelling

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Synonyms

Building information modelling of construction; Building product modelling

Definition

The modelling of construction process can be defined as a procedure of collecting tangible and intangible data that is needed for a successful operationalization of construction activities. For decades, construction process modelling has largely remained manual and or partially information technology centric. This article discusses the use of digital information modelling tools as a medium for modelling construction processes as a way of improving performance in the built environment.

Introduction

The worldwide realization of the potential benefits associated with the deployment of building information modelling (BIM) (Jamil and Fathi 2018) has created, inter alia, a destructive force of unrealistic framing and hype (Fox 2014) attributable to

stifling process modelling of construction activities. On one hand scholars claim that BIM has proven and outstanding results in construction processes by enhancing knowledge sharing with regard to a building or facility throughout its life cycle from the conceptual design to facility management (Jamil and Fathi 2018; Khosrowshahi and Arayici 2012; Aranda-Mena et al. 2009; Lindkvist 2015). On the other hand, scholars believe that as innovative as BIM strategies could be (Murphy 2014), the construction industry still requires a massive effort with regard to modelling information related to processes pertinent to delivery of projects (Fox 2014; Motawa and Almarshad 2015; Bosch et al. 2015). Currently the construction industry uses pervasive data modelling tools such as digital cameras, tablet computers and other handheld gadgets, drones, and the like (Aziz et al. 2017) to capture data on building product and processes. This implies that the industry uses varied digital gadgets to capture and generate data of varied sort at any stage in the construction process; hence, the industry remains largely fragmented in the way it handles construction data (The Infrastructure and Projects Authority 2016). While the technology to capture building product data is fully developed, there is a challenge related to modelling tacit knowledge from a section of experienced construction management workforce. The introduction of the BIM strategy of construction delivery, as is the case with Level 2 BIM initiative of the UK government of 2016 (The Infrastructure and Projects Authority 2016), essentially takes away the most familiar and user-friendly means of modelling knowledge and ideas (paper, pen, and the like) on construction processes. The unintended consequences of using BIM have been the massive loss of knowledge because current technological systems are ill-prepared to capture data from highly experienced workers who are disinterest in a gadgetry-driven work environment. This article, therefore, explains the necessity of construction processes modelling and how it should be implemented using international standards. Without the use of international standards, the construction industries miss-out on the benefits of operating in a digital work environment because of the clumsiness associated with modelling of information using manual methods.

Challenges of Modelling Contextual and Social Competencies Necessary for Managing Construction Processes

"If it isn't broke, don't fix it" – construction industry mantra

As the worldwide construction industry undergoes a paradigm shift driven by the adoption of BIM (Eadie et al. 2015), some owners and operators are yet to discover the added value of BIM in their respective areas of interest, especially the information management within their organizations (Bosch et al. 2015). Anecdotal evidence shows that experienced construction management workforce have a rule of thumb that prefers proven construction processes to new ones because the former have served the industry over the years need not be changed for the sake of change than the later. Meaning that before introducing change, there should be evidence showing that new approaches could outperform current ones. It could, therefore, be argued that modelling process information using BIM requires robust scrutiny and evidence-based data that could sway industry decision-makers to adopt it.

According to Kassem et al. (2015), BIM is the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way. The critical issue has been to operationalize the interoperable know-how that underpins decision-making on construction processes so as to ease the justification and estimation of the resource consumable at a given time period of the project. Even though there is a perception that BIM uptake would continue increasing in the short term, enforced Level 2 BIM (BS 1192-4 2014) coupled with client demand has been the cardinal drivers of BIM thus far (Eadie et al. 2015). However, the increase in the uptake of BIM in its current form does not address the challenges of modelling processes that are critical to smooth operationalization of construction projects. Construction processes, by nature, encompass technical, contextual, and

behavioral (or social) competencies that are necessary to achieve project excellence (International Project Management Association (IPMA) 2018). It implies that one should manage people, processes, resources, results as well as project purpose. However, for construction process specialists to model the necessary data from the desired level of competencies, they would have to utilize and go beyond current BIM standards and guidelines (BS 1192-4 2014; BS 1192:2007+A2 2016; ISO 10303-1 1994; ISO 16739 2013). Such an achievement is desired, but highly unrealistic as at 2018 because the industry largely hovers on Level 2 BIM under the COBie code of practice (Eadie et al. 2015; BS 1192-4 2014; Specialist Engineering Contractors' (SEC) 2014). Therefore, the challenge for modelling construction process information lies with the top-down BIM initiative strategy because it focuses more on strategy and less on data process modelling.

Frailty of Top-Down BIM Initiatives

The full benefits of BIM for construction management could only be realized when the industry moves to a fully interoperable model (Level 3 BIM of COBie code of practice) – by file sharing system or by database system, with the capability to model technical and commercial data for the whole project (Specialist Engineering Contractors' (SEC) 2014). Such an aspiration could be realized if construction management research could redirect the energy on process data modelling using international standards (BS 1192-4 2014; ISO 10303-1 1994; ISO 16739 2013). Currently, construction processes have unlimited approaches through which they could be modelled mainly because of the varied nature of data types (ISO 10303-1 1994). For instance, construction process model would not only depict schedule data but also contract documentation to model legal information necessary to operationalize the project (Jamil and Fathi 2018); contracts to model risks and responsibilities of project stakeholders (Construction Industry Council (CIC) 2018); and the expert knowledge to model best practice from construction managers (Khosrowshahi and Arayici 2012; Kähkönen and Rannisto 2015). Khosrowshahi and Arayici (2012) opined that BIM implementation is a major change management task, involving diversity of risk areas. The identification of the challenges and barriers is therefore an imperative precondition of this change process. While generic preconditions have been explored over the past decade, there is a gap in addressing fundamentals of process modelling with regard to construction processes and the competencies of managing projects. The major factor has been the "abstract" nature of the data types needed to model processes.

Despite the realization of the need to revisit the modelling of construction processes, BIM implementation strategies tend to focus on organizational, cultural, and management-related action points. For instance, Khosrowshahi and Arayici (2012) proposed three structured patterns to systematically tackle technology, process, and people issues in BIM implementation. These are organizational culture, education and training, and information management (Khosrowshahi and Arayici 2012). Similarly, Aranda-Mena et al. (2009) identified mechanisms of informing project management practice on the business benefits of building information modelling (BIM) adoption. They found that there was a need for "shared understanding on business drivers to adopt BIM for managing the design and construction process of building projects ranging from small commercial to high-rise" (Aranda-Mena et al. 2009). Motawa and Almarshad (2015) opined that the "next generation of BIM should seek to establish the concept of Building Knowledge Modelling (BKM)". They argued that BIM applications in construction, including those for asset management, had mainly been used to ensure consistent information exchange among the stakeholders (Motawa and Almarshad 2015). Yet BKM is needed to utilize knowledge management (KM) techniques into building models to advance the use of these systems (Motawa and Almarshad 2015). Motawa and Almarshad (2015) proposed a "BIM module to capture relevant information and case-based reasoning (CBR) module to capture the operational knowledge of maintenance activities". The structure of the CBR module was based on analysis of a number of interviews and case studies conducted

with professionals working in public BM departments (Motawa and Almarshad 2015). The suggestion departs from the international initiative articulated in (ISO 16739 2013); the critical issue is to address the challenge at data model level using Express modelling language. Even though the current BIM strategies promote data sharing, knowledge is kept by those who possess it, mainly because their decisions are not easily modelled due to lack of mechanisms to do that. Project management practices in construction refer to, inter alia, process-based modelling in order to plan and control the delivery of projects as efficiently as possible and within health and safe working environment. The ISO standard for IFC, using STEP modelling language, has established the route way to neutral modelling of building information of all sorts, including both explicit and tacit knowledge. However, the challenge has been the creation of user-friendly interfaces that could model tacit knowledge, within a dynamic construction management environment.

Approach to Developing a Procedure of Modelling Construction Processes

The main approach to developing a procedure of modelling construction processes involved collection of information from practitioners and academics (Saunders et al. 2009; May 2011), whereby questions were asked with regard construction processes and the detailed explanation and justification (Rosenthal 2016). The model information came from practitioners in the United Kingdom (UK) (Strata.com 2017; Rose et al. 2015; Sounderpandian 2008). Professional construction personnel were asked to explain how BIM implementation strategies address modelling of construction management processes with a view to improving the capturing both tangible and intangible information. Six themes have been used to explain, and they are (i) perception of innovation in modelling construction process data, (ii) value addition of data models to construction processes, (iii) perception of ultimate benefits of data models, (iv) modelling systems information, (v) modelling sustainable construction processes, and (vi) models based on international standards.

Perception of Innovation in Modelling Construction Process Data

The initial theme was to assess the perception of innovation in modelling construction process data. By innovation, it was envisaged that BIM could be perceived as a vehicle for modelling technical as well as commercial data (Murphy 2014). The results indicated that there is a strong perception that BIM was addressing strategic competencies at the expense of technical and operational processes. Discourse on modelling construction processes was only perceived to imply "Gantt charts" and schedule related data. In reality, there are a myriad of key competencies for construction process which would have been modelled, but the means to model them is limited at best.

Value Addition of Data Models to Construction Processes

According to Bosch et al. (2015), owners and operators are presumably yet to discover the added value of BIM for maintenance and information management within their organizations. Construction processes were more complex than building maintenance; hence, it was critical to explore "sources of inefficiency and ineffectiveness" of BIM. Bosch et al. (2015) found that current added value of BIM in the operations stage was marginal, mainly because of the challenges of alignment between the supply of and demand for information and the context-dependent role of information (Bosch et al. 2015). Therefore, the second question related to the perception that data models could add value to construction processes. The rationale for this question was to assess how BIM was assessed with relation to existing construction processes. Practitioners felt that value addition was represented through 4D simulation of schedule and resource planning. The same reason was cited by Li et al. (2015). The industry struggles to capture data models with information from the wider supply chain on construction objects. This weakness is compounded by the scanty nature of

construction and commercial data because the nature of this type data is mainly abstract and dynamic.

Perception of Ultimate Benefits of Data Models

Lindkvist (2015) opined that "BIM offers a holistic approach to building projects across a number of practices". However, projects have a relatively short-term benefit of using BIM with 80 per cent of the cost of an asset spent in operations. The ultimate benefit of BIM is when the information which the end user inherits from building projects creates value that occurs over a long period of time (Lindkvist 2015). Therefore, the questions regarding the perception of ultimate benefit of data model were aimed at assessing if construction practitioners had a long-term view of BIM. The response shows that 83% felt that construction management processes are critical in assuring the asset owner throughout the life cycle of the product. However, there was an overemphasis on the schedule, resource management, and commercial management.

Modelling Systems Information

Practitioners were asked how the deal with data models for various building systems necessary to operate a facility. Love et al. (2015) argued that BIM models emphasized the integration of software packages for architectural, structural, heating ventilation and air conditioning, and hydraulics, mainly because such elements have scale, geometry, and can be visualized. They argued that there were many systems with no scale or geometry and that they could not be visualized (Love et al. 2015); yet they are equally vital to the development of facilities. Therefore, practitioners argued that they buy off-the-shelf data models for systems information. The response shows that just like construction practitioners found it hard to model systems information, the same goes for construction management processes. It is prudent to learn from systems information models (SIM) and use a system of isolating classes that have not been instantiated.

Modelling Sustainable Construction Processes

For BIM to make a positive impact on sustainable construction, it would have to facilitate the modelling to Level 3 (BS 1192-4 2014; Specialist Engineering Contractors' (SEC) 2014; Alwan and Gledson 2015). In such a situation, the role of modelling standards such as COBie cannot be underestimated (Alwan and Gledson 2015). Therefore construction practitioners were asked if they were modelling construction processes that enhanced sustainability in the industry. Construction practitioners felt that they had not reached the stage where they could model all elements and processes to promote sustainable construction. This shows that there is a realization that process of instantiating particular classes within existing data schema such as COBie has been challenging, meaning that models that claim to contain robust building data have less information than they purport to possess.

Models Based on International Standards

Construction practitioners were asked about the role of international modelling standards for capturing construction process models. Alwan and Gledson (Alwan and Gledson 2015) assessed the use of COBie data schema for building asset modelling. Hence, the question on the role of standards was critical to this research. The response shows that construction practitioners had a strategic awareness of the role that international standards on data models played in the construction industry. However, the perception of standards was attributed to regulating how the industry and its stakeholders conducted themselves in the BIM working environment. The response indicates that there has been a gap as to how industry could contribute to the use of data models such as ISO 10303-1 (1994) and ISO 16739 (2013), which focus on building product and process representation.

Discussion of the Procedures for Modelling Construction Process

Currently, the industry should rely on BIM as a way of modelling construction processes because

of the ability to capture both tangible and intangible data. However, there is a challenge with the current BIM schema because its construction management processes largely remain outside data models because of the abstract nature of the data that represents the said processes. For example legal information of a construction project cannot be modelled as an "object," yet it is critical to the construction process. Legal information is of abstract data type, critical to the management of stakeholder responsibilities, but has challenges to model within the BIM environment (Olatunji and Akanmu 2015). Kähkönen and Rannisto (2015) argued that construction project management is heavily built around document control and relating events such as change orders, submittals, transmittals, and requests for information; hence, there is a reliance on electronic data/document management systems (EDMS).

However, it could be argued that EDMS offer a limited solution to modelling construction processes. This implies that EDMS do not fully mitigate software interoperability challenges of a typical construction process. EDMS do suffer from the lack of software interoperability, because it only speeds up the manual way of working and does not fundamentally address interoperability as per international BIM standards. Davies et al. (2017) opined that the potential for BIM to improve processes is documented, but few projects realize that potential.

This is because construction processes are laden with a myriad of undocumented tasks, events, and decisions related to logistics, health and safety (Riaz et al. 2017), and the impact on delivery schedules, and the supply chain and the milestones. Such challenges cannot be ignored any longer for the industry to move to Level 3 BIM (Specialist Engineering Contractors' (SEC) 2014) (SEC, 2014), or else the BIM working environment would continue being insignificant in the operational life of facilities (Edirisinghe et al. 2017). It can be argued that adopting strategic protocols for implementing BIM has an insignificant drive on the process of data modelling (Mei et al. 2017). Making BIM mandatory does not address the challenges of modelling construction processes; this should be a focus of researchers within that field (Day 2011).

Therefore, the goal for improving modelling construction process needs to focus on meta-analysis of the pertinent data in Level 3 BIM (Noor and Yi 2018); else the status quo is likely to have a negative impact on future construction workers because knowledge is being lost through a natural process such as retirement of the most experience people (Sfakianaki 2015), whose knowledge cannot be captured and shared with new entrants to construction management.

Conclusion

As the construction industry continues to claim benefits for adopting BIM, the modelling of construction management processes and their embedded knowledge remain stagnant. This is mainly because of the abstract nature of the data that typify construction processes. As a result, construction processes are laden with a myriad of undocumented tasks, events and decisions related to logistics, health and safety, and the impact on delivery schedules and the supply chain and the milestones. Such challenges cannot be ignored any longer for the industry to move to Level 3 BIM, or else the BIM working environment would continue being insignificant in the operational life of facilities. Strategic protocols for implementing BIM have an insignificant drive on the process of data modelling. Making BIM mandatory does not address the challenges of modelling construction processes.

Cross-References

- ▶ Interactive Computer Graphics and Model-View-Controller Architecture
- ▶ Open Source 3D Printing, History of
- ▶ Technologies for the Design Review Process
- ▶ Virtual Reality Systems, Tools, and Frameworks

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Constructionism

► PBL-Based Industry-Academia Game Development Education

Constructivism

► PBL-Based Industry-Academia Game Development Education

Consumers

► Game Prosumption

Contemporary Computer Shogi

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Synonyms

Chess variant; Japanese chess

Definition

Computer shogi is a field of artificial intelligence involving the creation of software programs capable of playing shogi, the Japanese form of chess.

Introduction

Computer shogi was first developed in late 1974 by Takenobu Takizawa and his research group. It has been steadily improved by researchers and commercial programmers using game tree making and pruning methods, opening and middle game databases, and feedback from research into tsume-shogi (mating) problems. The strength of computer shogi has been measured by watching and studying many games between computer programs and professional players and has reached that of top-level human players. In the remainder of the article, section "Computer-Computer Games" describes the history of computer-computer games. Section "Computer Shogi Players" describes the programs that played them, and section "Computer-Human Games" describes the history of human-computer games.

Computer-Computer Games

Yoshiyuki Kotani and Takenobu Takizawa jointly established the Computer Shogi Association (CSA, Takada 2014) in 1986. This organization started organizing computer shogi tournaments called the World Computer Shogi Championships (WCSCs), in 1990 (Takizawa and Grimbergen 2001). The tournaments are supported by Nihon Shogi Renmei (the Japan Shogi Association or JSA).

The following are the policies of WCSCs declared on January 23, 2012.

1. The WCSC tournaments are held for the purpose of determining the strongest computer shogi program at the time under conditions of fair and impartial operation.
2. The CSA imposes no restrictions on the hardware or software of any WCSC entrant or on persons entering the hardware or software.
3. The CSA supports the interchange of ideas among hardware/software developers who enter their products in WCSC tournaments.

Table 1 shows a summary of WCSC results. Ten programs have won the tournaments. Kanazawa Shogi has won five times, IS-Shogi and Gekisashi four times each, YSS three times, Bonanza and GPS Shogi twice each, and Eisei Meijin, Morita Shogi, Bonkras, and Apery once each. The 22nd WCSC was held on May 3–5, 2012. Forty-two teams (including one invited) entered, with GPS Shogi winning the championship for the second time. The 23rd WCSC was held on May 3–5, 2013. Forty teams (including

Contemporary Computer Shogi, Table 1 Results of the world computer shogi championships

No.	Date	Number of Participants	Winner	Second	Third
1	1990.12.2	6	Eisei Meijin	Kakinoki	Morita
2	1991.12.1	9	Morita	Kiwame	Eisei Meijin
3	1992.12.6	10	Kiwame	Kakinoki	Morita
4	1993.12.5	14	Kiwame	Kakinoki	Morita
5	1994.12.4	22	Kiwame	Morita	YSS
6	1996.1.20–21	25	Kanazawa	Kakinoki	Morita
7	1997.2.8–9	33	YSS	Kanazawa	Kakinoki
8	1998.2.12–13	35	IS	Kanazawa	Shotest
9	1999.3.18–19	40	Kanazawa	YSS	Shotest
10	2000.3.8–10	45	IS	YSS	Kawabata
11	2001.3.10–12	55	IS	Kanazawa	KCC
12	2002.5.2–5	51	Gekisashi	IS	KCC
13	2003.5.3–5	45	IS	YSS	Gekisashi
14	2004.5.2–4	43	YSS	Gekisashi	IS
15	2005.5.3–5	39	Gekisashi	KCC	IS
16	2006.5.3–5	43	Bonanza	YSS	KCC
17	2007.5.3–5	40	YSS	Tanase	Gekisashi
18	2008.5.3–5	40	Gekisashi	Tanase	Bonanza
19	2009.5.3–5	42	GPS	Ootsuki	Monju
20	2010.5.2–4	43	Gekisashi	Shueso	GPS
21	2011.5.3.–5	37	Bonkras	Bonanza	Shueso
22	2012.5.3–5	42	GPS	Puella alpha	Tsutsukana
23	2013.5.3–5	40	Bonanza	Ponanza	GPS
24	2014.5.3–5	38	Apery	Ponanza	YSS

Kanazawa is the successor to Kiwame
Puella alpha is the successor to Bonkras

Contemporary Computer Shogi, Table 2 22nd WCSC final results (May 5, 2012)

Rank	Player	1	2	3	4	5	6	7	Pt	SB	MD
1	GPS Shogi	6+	5+	8+	7+	3+	2–	4+	6.0	17.0	12.0
2	Puella alpha	5+	7+	6–	4–	8+	1+	3+	5.0	16.0	9.0
3	Tsutsukana	8+	6+	7–	5+	1–	4+	2–	4.0	11.0	6.0
4	Ponanza	7+	8+	5–	2+	6+	3–	1–	4.0	11.0	5.0
5	Shueso	2–	1–	4+	3–	7+	8–	6+	3.0	9.0	3.0
6	Gekisashi	1–	3–	2+	8+	4–	7+	5–	3.0	8.0	2.0
7	YSS	4–	2–	3+	1–	5–	6–	8+	2.0	5.0	0.0
8	Blunder	3–	4–	1–	6–	2–	5+	7–	1.0	3.0	0.0

Contemporary Computer Shogi, Table 3 23rd WCSC final results (May 5, 2013)

Rank	Player	1	2	3	4	5	6	7	Pt	SB	MD
1	Bonanza	5+	8+	6+	2–	7–	4+	3+	5.0	16.0	10.0
2	Ponanza	8+	7+	5–	1+	6+	3–	4+	5.0	15.0	9.0
3	GPS Shogi	7+	6+	8+	5+	4–	2+	1–	5.0	14.0	8.0
4	Gekisashi	6+	5–	7+	8+	3+	1–	2–	4.0	11.0	5.0
5	NineDayFever	1–	4+	2+	3–	8+	7–	6–	3.0	10.0	4.0
6	Tsutsukana	4–	3–	1–	7+	2–	8+	5+	3.0	6.0	2.0
7	Shueso	3–	2–	4–	6–	1+	5+	8–	2.0	8.0	0.0
8	YSS	2–	1–	3–	4–	5–	6–	7+	1.0	2.0	0.0

one invited) entered, with Bonanza winning the championship for the second time. The 24th WCSC was held on May 3–5, 2014. Thirty-eight teams entered, with Apery winning the championship for the first time.

The 22nd WCSC tournament had 42 computer players (including one invited). GPS Shogi was the winner, but if Ponanza had beaten GPS Shogi in the last game, then Tsutsukana, Ponanza, or Puella alpha would have been the winner. The final round results are shown in Table 2.

The 23rd WCSC tournament had 40 computer players (including one invited), and Bonanza was the winner. After the preliminaries had narrowed the field down to eight, those eight played a round robin (each player playing the other seven players once) to determine the winner. The results were close, with the top three programs losing twice, while every program won at least once. This indicates that the top programs were comparable in strength. For example, GPS Shogi would have been the winner if it had won the last game. If Shueso, which finished seventh, had beaten YSS, which finished eighth, in the last game, Ponanza would have been the winner. The final round results are shown in Table 3.

The 24th WCSC tournament had 38 program entrants, with Apery being declared the winner. Both Apery and Ponanza won five games and lost two, but Apery got the nod on tiebreak, even though YSS beat both of them. Ponanza was thus runner-up as it had been the year before, while YSS had to settle for equal third place. The YSS program entered the WCSC tournaments 23 times and never finished worse than equal eighth in any of them. Both Ponanza and NineDayFever would have won the tournament if they had won their last game. The final round results are shown in Table 4 (Takizawa 2014).

Computer Shogi Players

Most computer shogi programs carry out minimax tree searches enhanced by techniques in computer chess and by other completely new ideas. In this

Contemporary Computer Shogi, Table 4 24th WCSC final results (May 5, 2014)

Rank	Player	1	2	3	4	5	6	7	Pt	SOS	SB	MD
1	Apery	4–	6+	7+	5+	3–	2+	8+	5.0	23.0	15.0	10.0
2	Ponanza	5+	7+	6+	8+	4+	1–	3–	5.0	23.0	14.0	10.0
3	YSS	6–	5–	4–	7+	1+	8+	2+	4.0	24.0	13.0	8.0
4	NineDayFever	1+	8+	3+	6–	2–	7+	5–	4.0	24.0	12.0	7.0
5	Gekisashi	2–	3+	8+	1–	7–	6+	4+	4.0	24.0	11.0	7.0
6	Bonanza	3+	1–	2–	4+	8+	5–	7–	3.0	25.0	8.0	4.0
7	Tsutsukana	8+	2–	1–	3–	5+	4–	6+	3.0	25.0	7.0	3.0
8	N4S	7–	4–	5–	2–	6–	3–	1–	0.0	28.0	0.0	0.0

section, "The Art of Computer Shogi" describes the art of computer shogi, and "Brief Description of the 24th WCSC Winner Program" gives a brief description of the 24th WCSC winner program, Apery.

The Art of Computer Shogi

Many computer shogi programs use alpha-beta pruning, PVS (principal variation search), quiescence search, aspiration search, null move (forward) pruning, futility pruning, killer heuristic, history heuristic, iterative deepening, transposition hash tables, and singular extension, adopted from chess programs. A minimax tree for shogi usually has a larger branching factor in the endgame than in the opening. The row branching factor on average is about 80, and it is known that the factor is effectively reduced to about 3 by using pruning techniques.

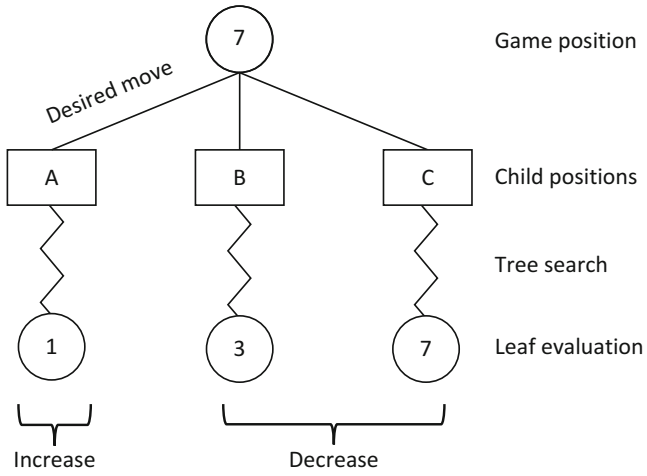
Large-Scale Optimization for Evaluation Functions

Heuristic search is a powerful method in artificial intelligence. In the case of chess, it is capable of deciding a plausible move after expanding a large minimax game tree with heuristic leaf evaluations. The quality of such heuristic evaluations is crucial for making strong computer chess players. Researchers have made substantial efforts in a quest to create effective evaluation functions by using machine learning techniques in various games (Fürnkranz 2001). Shogi is probably one of the more interesting games to see successful examples of machine learning of evaluation functions.

In 2006 Bonanza, a program developed by Kunihito Hoki, demonstrated a practical use of machine learning of evaluation functions in WCSC and won the competition. The learning method consists of subsequent steps: prepare a set of grandmaster game records, a search function, and a linear weighted evaluation function and decide the initial weights in the function. Give positions in game records to the search function and compute agreements between the search results and the recorded moves. If more search results agree with recorded moves, then the weights are probably better. To adjust the weights, iterative procedures of numerical minimization techniques are carried out. In this way, the learning procedures optimize the weights to control the minimax tree search results.

Figure 1 illustrates such a learning procedure as applied to chess. Assume the game position has three legal moves and a grandmaster has just played a move to reach child position A. The procedure carries out a tree search to examine the three child positions that could have been reached on the move and obtains search value 1 for position A, 3 for position B, and 7 for position C. In this case, the tree search recognizes that C is the best, B is the second best, and A is unfortunately the worst. Under this circumstance, the learning procedure adjusts the value of the leaf evaluation rooted at A higher, and those rooted at B and C lower.

Such learning methods were investigated in computer chess because the game scores of grandmaster games were a common way to learn chess, not only for computer players but also human players. Assume that one has a position reached in a game score and the desired move is the one that was actually played. A chess program



Contemporary Computer Shogi, Fig. 1 An illustration of evaluation learning procedure

has an evaluation function $e(p,\boldsymbol{w})$, where p is the game position and the feature weight vector $\boldsymbol{w}$ contains the parameters to be adjusted. Now consider a simple intuitive goal: make the results of a one-ply search agree with the desired move, where the search selects the highest evaluation value. Thus, w should be adjusted so that the desired move has the highest evaluation of all the moves. This goal can be written as a minimization problem with an objective function:

$$J_H(\boldsymbol{w}) = \sum\nolimits_{m'} H(e(p.m', \boldsymbol{w}) - e(p.d, w)) \quad (1)$$

Here, $p.m$ is the child position reached after move m, d is the desired move, index m' runs for all legal moves except d, and $H(x)$ is the Heaviside step function, i.e., $H(x)$ equals 1 if $x \geq 0$ and 0 otherwise. Because this objective function counts the number of moves that have an evaluation value greater than or equal to that of the desired move, a better w can be found by minimizing Eq. 1.

In chess, several studies have been made on the basis of the objective function Eq. 1 (e.g., see Meulen 1989). However, numerical minimization seemed to present practical difficulties. To overcome such difficulties, Marsland (1985) used some continuous functions instead of the non-continuous step function $H(x)$ so that the gradient vector would help to reduce the function value numerically. Moreover, Hsu et al. (1990) used evaluations of leaf positions of the principal variations instead of using the direct evaluations of p. m' and $p.d$ to get better learning performances. Furthermore, Tesauro (2001) used a continuous approximate of the step function. Although it seemed that such learning methods would be able to adjust hundreds of weights to have reasonable values, fully automated learning of the chess evaluation functions still remains a challenging goal. For example, developers have reported that the majority of the features and weights in Deep Blue were created/tuned by hand (Campbell et al. 2002).

It turned out that such machine learning by using grandmaster games was also useful in shogi. Hoki et al. proposed a method, Minimax Tree Optimization (MMTO, Hoki and Kaneko 2014), to learn the evaluation function of a practical alpha-beta search program. They used grid-adjacent update, equality constraint, and l_1 regularization to achieve scalability and stability. Their objective function with modified gradient vectors was to be able to optimize the values of 13 shogi pieces with reasonable numerical accuracy and to adjust 40 million parameters for strength. Hoki had proposed an earlier version of MMTO in 2006 (Hoki et al. 2006) and implemented it in the shogi program Bonanza, winning the WCSC championships in 2006 and 2013. After 2006, it became famous and has often been referred to as the "Bonanza method." Recent computer shogi players have evaluation functions, where the weights are learned from professional players' game records.

Many machine learning techniques that do not require grandmaster game records have also been applied to shogi. However, the adjustment of the full weights in the evaluation function remains a challenging goal. The studies that have been published so far have adjusted only piece values or a small part of the feature weights in the evaluation functions.

Consultation Algorithm

Much research that has compared problem-solving by groups with that by individuals has been carried out in the field of cognitive science. Shaw conducted an experiment that compared the efficiency of problem-solving by a group and that by individuals in 1932, using a missionaries-and-cannibals problem (Shaw 1932). Many researchers used simple logic problems of this type from the 1940s to the 1950s and found that groups were able to outperform individuals. These results supported the old proverb that "two heads are better than one."

Althöfer et al. (2003) have carried out studies since 1985 on chess or the game of Go in research on the selection of moves in thought games. They proposed a system called 3-Hirn that consists of two computer programs and a human chess player, where the human selects a move from the programs' outputs. They demonstrated that the system enabled the programs to improve their ratings by about 200 points. They carried out almost the same experiments in Go or other games, and through them they demonstrated the system's efficiency.

From this, one gets the idea that an ensemble of game programs may be able to play a better move than an individual program does. Although many sophisticated ensemble-based systems in computer science have been built with the aim of achieving better performance, designing such systems in computer games still remains a challenging task.

One of the methods that could be used to build such an ensemble-based system in shogi is the majority voting method. Obata et al. (2011) reported that majority voting in three famous programs (YSS, GPS Shogi, and Bonanza) produced better games than any of the three programs played individually. They also proposed a pseudorandom number (PRN) ensemble method. In this method, the ensemble is built using multiple copies of one base program, and each copy is diversified by adding random numbers to the evaluation function of the base program.

They researched these methods where a machine chose a move automatically without human intervention. Here, they defined "consultation" as a process that generates one answer on the basis of conclusions obtained by using two or more different thinking processes. They considered various methods of "consultation" by computers and concluded that the "majority voting system" might be one of the simplest systems, in which a majority opinion is adopted from various opinions. Although the system was very simple, they showed its effectiveness in their experimental results.

Sugiyama et al. (2011) examined another approach, one of combining multiple programs. In carrying out this approach, they used a new selection rule that selects the player that yields the highest evaluation value. They called this method the "optimistic ensemble system" and reported that it often outperformed the "majority voting system" when multiple computer programs were prepared by using the PRN ensemble method.

Hoki et al. (2014) examined these ensemble systems in computer chess. The results of their experiments showed that both the "majority voting system" and the "optimistic ensemble system" were efficient in computer chess.

Two advantages of the "consultation" method are known. First, it can use a loosely coupled computing environment. Because it is simple and fault tolerant, it can always be an alternative when a large-scale distributed environment is available for strength. Second, it has a high degree of generality and is orthogonal to other parallel search techniques. It can function efficiently with multiple different programs even when each program utilizes parallel search techniques.

Research on consultation systems in games is still in the infancy stage. So far, the effectiveness of simple majority voting has been examined only for shogi and chess, where computer players perform minimax tree searches, and in Go, where

computer players perform Monte Carlo tree searches.

Realization Probability Search

When computer players start to play a shogi game, moves previously made by professional players have already been collected and categorized and their probabilities calculated in the program. These moves include capturing and recapturing pieces, promoting a rook or bishop to gain a material advantage, checking, and so on. During the course of the game, the players control tree expansions based on these probabilities, i.e., if the multiplied probability of a move history from the root to the current position is higher than a threshold, then the program searches deeper. Tsuruoka et al. (2002) proposed this algorithm and implemented it in the Gekisashi program, and with it they won WCSC titles in 2002, 2005, 2008, and 2010.

Distributed Parallel Search

The first computer shogi program using a multiprocessor system was the Super Shogi program developed by Hisayasu Kuroda in 1997, which used an eight-computer system. In 2012, the GPS Shogi program developed by Tetsuro Tanaka and Tomoyuki Kaneko et al. used 320 processors (666 cores in total) and won the 22nd WCSC title (Kaneko and Tanaka 2012).

Tsume-Shogi (Mating Problem) Solver

In addition to ordinary minimax searches, a computer player often uses an additional search function dedicated to finding a long mate sequence. The techniques used in tsume-shogi functions derive from studies on solving such mating problems. Unlike in chess, in shogi the number of possible moves in the endgame is the same as the number of possible moves in the middle game. Therefore, an efficient AND/OR tree search algorithm are needed for solving tsume-shogi problems. Recent state-of-the-art solvers employ the df-pn search algorithm proposed by Ayumu Nagai, which is capable of solving most existing tsume-shogi problems (Kishimoto et al. 2011). Computer players also often use a hard-coded function dedicated to finding one- or three-ply mate sequences.

Brief Description of the 24th WCSC Winner Program

The Apery program, which was developed by Takuya Hiraoka, had a Stockfish-like search function (Stockfish is a strong open source chess program). Over the past 3 or 4 years, the effectiveness of the chess search function in shogi has become famous, notwithstanding the differences in the rules between the two games. Using chess search techniques, Apery achieves performance improvements by using additional functions such as a one-ply mate search function.

Apery also has a Bonanza-like evaluation function. It evaluates shogi positions by using a three-piece square table that evaluates all combinations of a king and other two-piece locations. Because the combinations always contain one or two kings, the evaluation function is sensitive to the distance between kings and other pieces. In shogi, the distance from a king is a vital feature. Most shogi pieces have limited mobility, and those that are located far from the kings are for the most part useless, especially in the endgame. Since the source codes of Bonanza version 4 appeared online in 2009, it seems that the evaluation function's performance has advanced in both computational speed and evaluation accuracy. Hiraoka believes that Apery's evaluation function does not reach the highest level and has some room to improve. One of the difficulties in creating such a highest-level evaluation function is that machine learning of evaluation functions requires a tremendous amount of computational resources.

Hiraoka believes that Apery's rating is 200–250 points below that of the top programs and considers that Apery won the 24th WCSC for a number of reasons. First, the tournament concluded with a round robin of eight entrants, so only seven games determined the tournament winner. Second, on the basis of a "pawn toss" method, Apery moved first four times and second three times. This is important because the player moving first has the initiative. Statistics show that

in professional shogi, the player who moves first wins about 52 % of the time; Apery's corresponding percentage playing against other programs is 56 %. Third, a relatively short time control was used in the tournament (25 min for the whole game with no time-shortage countdowns), and while the top programs utilized a loosely coupled computing environment, Apery did not. Because Apery was free from distributed computing overheads, the short time control increased its winning chances. Fourth, Apery played the openings quite strongly since its opening "book" contained the moves computer players had previously played that were available in floodgate (http://wdoor.c.u-tokyo.ac.jp/shogi/). On the other hand, the other entrants did not seem to focus on the best moves as given in opening books.

Computer-Human Games

In 1997, when IBM's "Deep Blue" program beat the world chess champion Gary Kasparov in a six-game match, the strongest computer shogi program was only a little stronger than an average club player. The top programs reached the professional 4-dan level in 2010 and have now reached the top human-player level. Table 5 summarizes the results of computer-human games that have been played to date.

The first game between a female professional shogi player and a computer shogi program was an exhibition game played on July 29, 2001 at the Mind Sports Olympiad in Japan. Each player had 15 min for the whole game plus a 60-s time-shortage countdown. Yamato Takahashi, the professional player, moved first and won her game against IS-Shogi. After the game she said, "IS-Shogi's strength is about 1-dan in the opening, 4- or 5-dan in the middle game, and 3- or 4-dan in the endgame. For the game as a whole it is not 1- or 2-dan but 3- or 4-dan."

On September 19, 2005, Hokkoku Shimbun sponsored a game between the TACOS program and Takanori Hashimoto, an 8-dan professional. Hashimoto eventually won, but TACOS had the

Contemporary Computer Shogi, Table 5 Game results: professional shogi players vs. computer shogi programs

Date	Event	Professional human player	Computer	Winner	Time control (countdown)
2007.3.21	Daiwa Shoken Hai Special Game	Akira Watanabe (Ryu-O titleholder)	Bonanza	Human	2 h (60 s)
2011.12.21	Den-O-Sen Practice Game	Kunio Yonenaga (Lifetime Kisei titleholder)	Bonkras	Computer	15 min (60 s)
2012.1.14	First Shogi Den-O-sen	Kunio Yonenaga (Lifetime Kisei titleholder)	Bonkras	Computer	3 h (60 s)
2013.3.23	Second Shogi Den-O-Sen	Koru Abe (4-dan)	Shueso	Human	4 h (60 s)
2013.3.30		Shin'ichi Sato (4-dan)	Ponanza	Computer	
2013.4.6		Kohei Funae (5-dan)	Tsutsukana	Computer	
2013.4.13		Yasuaki Tsukada (9-dan)	Puella alpha	draw	
2013.4.20		Hiroyuki Miura (9-dan)	GPS Shogi	Computer	
2013.12.31	Den-O-Sen Rematch	Kohei Funae (5-dan)	Tsutsukana	Human	4 h (60 s)
2014.3.15	Third Shogi Den-O-Sen	Tatsuya Sugai (5-dan)	Shueso	Computer	5 h (60 s) (chess clock)
2014.3.22		Shin'ya Sato (6-dan)	Yaneura-O	Computer	
2014.3.29		Masayuki Toyoshima (7-dan)	YSS	Human	
2014.4.5		Taku Morishita (9-dan)	Tsutsukana	Computer	
2014.4.12		Nobuyuki Yashiki (9-dan)	Ponanza	Computer	
2014.7.19–20	Third Shogi Den-O-Sen Rematch	Tatsuya Sugai (5-dan)	Shueso	Computer	8 h (60 s) (chess clock)

advantage in the middle game. After this the JSA prohibited professional players from playing against computer players in front of an audience without its authorization. In the same year, Gekisashi was invited to an amateur Ryu-O tournament. Placing 16th, it was evaluated as being comparable in strength to top-level amateur shogi players.

On March 21, 2007, a game was played between Bonanza and Akira Watanabe, holder of the prestigious Ryu-O championship title. Sponsored by Daiwa Securities, it was the first official game between a professional shogi player and a computer player since the abovementioned Hashimoto-TACOS game in 2005. It was a very close game, with Watanabe eventually winning. Watanabe recently said that he was lucky to win because in a critical position, a professional human player can find a winning move relatively easily, but this is not so for computer shogi programs.

On October 11, 2010, Ichiyo Shimizu, one of the top female professional players, lost a game against the computer shogi system Akara2010. The game was sponsored by Komazakura (JSA Ladies Professional Players Group), the Information Processing Society of Japan, and the University of Tokyo. Each player had 3 h for the whole game plus a 60-s time-shortage countdown. The Akara2010 system employed the majority voting method using four existing programs combined with a distributed search method (Hoki et al. 2013) to enable it to use a large number of computers.

The first Den-O-Sen was held on January 14, 2012. This was a game played between a retired professional, the late Kunio Yonenaga, and the Bonkras computer program that had won the 21st WCSC. The game was sponsored by the JSA, Dwango, and Chuokoron-Shinsha, Inc. Each player had 3 h for the whole game plus a 60-s time-shortage countdown. Taking advantage of having the initiative that comes with moving first, Bonkras won the game.

The second Den-O-Sen, sponsored by Dwango and the JSA and held in March–April 2013, matched five human players and five computer programs. Each player had 4 h for the whole game plus a 60-s time-shortage countdown. The programs had taken the first five places at the 22nd WCSC. Table 1 shows the match results. It had been predicted that the human players would win the match with four wins and one loss, but the prediction was wrong; the programs took the match with three wins, one draw, and one loss. It was a major surprise that the very high-ranking professional Hiroyuki Miura (9-dan) was defeated by GPS Shogi (Takizawa 2013).

The third Den-O-Sen (July 2014), like the second, matched five human players and five computer programs. The programs had taken first through fifth places at the first Den-O tournament (a November 2013 all-computer tournament sponsored by Dwango and the JSA), with Ponanza the winner. Again it was predicted that the human players would win the match with four wins and one loss, this time because the programmers had not changed their programs after the Den-O tournament and the professional players had had a chance to study them. But again the prediction was wrong; this time the programs took the match with four wins and one loss.

Summary

The top computer shogi programs have already come close to the top human-player level. About 10 years ago, Yoshiharu Habu, holder of the prestigious Meijin championship title, predicted that the top programs would get close to the top human-player level in 10 years. His words were prophetic. Many professional players now understand how strong top computer programs have become, as do many people who have seen the results of the Den-O-Sen competitions or read about them in newspapers.

Computer shogi programs have become the helpful partners of professional players, who now use them in their studies. For example, 8-dan Daisuke Nakagawa observed the 18th WCSC and also the exhibition game between the Tanase Shogi program (the tournament runner-up) and the top amateur player Yukio Kato, which Tanase Shogi won. After studying this game, Nakagawa won his next three games in professional

competition, including one against Akira Watanabe, one of today's very top-ranked players. Another example is 9-dan Toshiyuki Moriuchi, who studied Ponanza's moves and used them to beat the superior Yoshiharu Habu in their 2013 match for the Meijin championship title.

The game of chess as played between humans is still vibrant and active, although computer chess programs are now stronger than the strongest human players. The same thing is likely to happen in the next 5 years for the game of shogi. However, while computer programs have come closer to unraveling the deepest mysteries of chess than they have of shogi, the fathomless depths of both games will continue to challenge researchers in the future.

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► Computer Go

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Context

► Game Writer's Dilemma: Context vs. Story

Contextual Learning and Teaching

▶ Challenge-Based Learning in a Serious Global Game

Convergence

▶ Cross-cultural Game Studies

Conversion

▶ Virtual Reality Stereo Post-Conversion After Effects Workflow

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▶ On Computer Games About Cooking

Corona

▶ Protection Korona: A Game Design on Covid-19

Counter-Strike Global Offensive, an Analysis

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Synonyms

Esports; First-person shooter; Free-to-play; Loot box; Mod

Definition

First-person-shooter (FPS) = a genre of games where the camera focuses on a gun (or other weapon) where the objective is to eliminate specific targets.

E-sports = a sports competition with video games as the focus rather than traditional sports.

History of Counter-Strike Global Offensive

Counter-Strike: Global Offensive (often abbreviated as CS:GO) is a team-based online first-person-shooter for Windows, OS X, Linux, Xbox 360, and Playstation 3 platforms in 2012. CS:GO was developed and published by Valve (Moore 2018). Counterstrike was originally a mod for a game, also developed by Valve, called Half-Life. A mod is an unofficial change to a video game created by players of the game. Mods can range from changing the way a game looks to changing the way a gamemode would normally work, in essence creating its own unique identity.

Since the early 2000s, Counter-Strike has evolved into its own standalone game franchise. CS:GO. In 2018, Valve changed CS:GO's pricing

method, switching to a free-to-play model by using revenue from cosmetic items to supplant the up-front cost. Free-to-play games allow access to a large part of the gameplay activities without up-front monetization. In-game purchases for cosmetic items offset the lack of up-front revenue.

Counter-Strike's most popular feature is its online matchmaking. It is a 5v5 team-based game that involves two sides, called the Terrorists and Counter Terrorists. The Terrorists are responsible for planting a bomb and ensuring that it explodes, while the Counter Terrorists are responsible for defending bomb sites and defusing the bomb. Players do not respawn after they die. Each team must strategize and/or counteract the opposing team's plays and be able to break through enemy lines or keep their defenses up; however, the fast pace of Counter Strike means that constantly being able to communicate efficiently and thoroughly to teammates can prove to be a challenge. For example, if a team's takeover strategy failed, the team has to quickly think of a new strategy in order to adapt, rise, and overcome. There are many problems that a team must solve on the fly, but are not directly told. Some include communication, playing as a team, doing your part in the match, etc. There are many scenarios that make the game enticing enough that most seasoned veterans return season after season; the team that either kills all other players on the opposing team or blows/defuses the bomb wins the round. CS:GO has a large competitive scene. There are massive competitive tournaments with many different professional Counter Strike players that play for sometimes millions of dollars. These tournaments, such as DreamHack, ESL, and more, hold some of the most viewed e-sports tournaments.

CS:GO allows players to host their own servers that have their own modded game modes. Other fan-created game-modes include bunny-hop, which is hopping from platform to platform to reach the end in the fewest number of mistakes. There are some other game modes that have gathered an audience, but run on small private servers. There are other features that a large part of CS: GO's player base partake in. One of the major ones being skin trading. Skins are just customizable wraps that several artists develop. They can be obtained from loot boxes. A loot box is an item that holds several other random items that can be used to change an item's appearance, in-game equipment, and other gameplay elements. It is often used as a way to monetize a game further. Some forms of Loot Boxes have been speculated to be a form of gambling. Some exceedingly rare and exclusive items have been sold on markets for over $30,000 USD.

Counter-Strike: Global Offensive was well received by critics at the time of release, with most ranging from 8/10 to 9.5/10. It has a Metacritic score of 83 and a user score of 7.5 (Metacritic 2012). After an update in 2013, an economy around the in-game skins cultivated several websites that allowed users to gamble their skins, including underaged players. Valve took steps in the following months to dissuade gambling sites from operation. In 2018, several countries passed antiloot box laws as they determined that they were gambling; Valve changed the game in the Netherlands and Belgium to comply with these laws by preventing the opening of loot boxes.

Cross-References

▶ First-Person Shooter Games, a Brief History

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Covid-19

▶ Protection Korona: A Game Design on Covid-19

Creating Graphics

► Teaching Computer Graphics by Application

Credit Skipping

► Speedrunning in Video Games

Cross-cultural Game Studies

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Synonyms

Comparative studies; Convergence; Cross-cultural studies; Game studies; Globalization; Localization

Definitions

Cross-cultural game studies aim to compare and clarify differences and similarities of games and culture across two or more cultures on a regional or national level. The elements of culture in game studies are understood as a shared way of thinking, behavior, language, value, belief, and gaming practices, which surround game cultures in the form of games as cultural artifacts, or as parts of subcultures formed by specific communities. Current cross-cultural game studies investigate and compare game contents, game markets, the gaming industry and production, player behavior as well as game and player interaction. Methods range from qualitative analyses, such as comparative case studies, literature reviews, empirical interviews, and text analysis, to quantitative methods of surveys, statistical tests, and natural language processing. The perspective of studying games and their surrounding contexts from cross-cultural lenses has potential to expand new findings and knowledge on video games and culture.

Culture in Game Studies

Game studies are increasingly focusing on game culture in diverse local contexts (Liboriussen and Martin 2016). Whether physically or in cyber space, in this era of digital transformation, video games, their creation and distribution, content and gaming experiences are consistently crossing cultural boarders, showcasing the complexity associated with understanding games and their surrounding phenomena. This obvious integration and transmission of culture and games opened new perspectives to study and clarify the differences and similarities of games and culture as well as its transition in several regions, which is signified by an increase in cross-cultural aspects in game studies. This entry introduces the concept of culture and games, and current research on games and culture conducted through the lens of cross-cultural studies.

The concept of culture is notoriously hard to define. Culture has been considered from a variety of academic viewpoints and theories, characterized by several layers, levels, or dimensions (Hofstede 2011; Schwartz 1999), and scientists have discussed how cultures evolve through globalization (Reinecke and Bernstein 2013). The culture of video games has been shaped from various interdisciplinary perspectives, focusing on game cultures understood as games as cultural artifacts, or as parts of subcultures formed by specific gaming communities, defined by social practices, and through the discourses of the video game industry, media, and academia (Shaw 2010). Mäyrä (2010) views culture as a shared way of thinking, behavior, values, and gaming practices among individuals in the micro- and macro-levels of society. Such cultures result in forming subcultures, which are visible aspects of specific language use, behavior, and beliefs among a particular community. In terms of levels of games and culture, Elmezeny and Wimmer (2018), p. 82) introduce

three levels of defining game cultures: 1) the macro-level focuses on the overall culture of games, gamers, and gameplay in regional or national fields worldwide, 2) the meso-level focuses on culture among multiple games or communities with unified characteristics, such as PS4 gamers and Nintendo gamers, and 3) the micro-level focuses on culture of a specific game or community, such as World of Warcraft culture or German FIFA culture.

In contemporary society, video games are the latest form of cultural expression, helping us to understand modern culture and society (Muriel and Crawford 2018). As games are becoming a major cultural influence, game studies evolved not only as a field focusing on games, playing, and related phenomena (Mäyrä 2008, p. 11) but also hold the power to critically analyze power relations in our culture and society by studying game contents, audiences, and production processes (Nieborg and Hermes 2008). Current game studies are formed by six major domains: 1) studying games as artifacts or texts (e.g., Mäyrä 2008; Schell 2008; Juul 2011), 2) analysis of player behavior (Charles et al. 2005; Braun et al. 2016), 3) globalization and localization of the games industry (Consalvo 2006), 4) game development (Engström 2020), 5) gaming culture (Muriel and Crawford 2018), and 6) interaction between game and player (Caroux et al. 2015). However, few have examined games and related phenomena from a cross-cultural perspective, that is, sought the difference and similarities among game markets, game production and design, game content, as well as the meaning and perception on games by game designers and players in geographically and socially different contexts.

Looking at the current situation in concern of video games, game developers and platforms from different cultures, such as Tencent (China), Sony (Japan), EA (America), and Ubisoft (France), compete on a global level, targeting local and global audiences (Newzoo 2020). Games are frequently developed through collaboration across culturally diverse regions. Death Stranding was for example created by the prominent Japanese game designer Hideo Kojima collaborating with Western actors and artists (Game Media 2020). Game contents produced in one culture are enjoyed in other cultures, for example games developed in East Asia are consumed by Western audiences (Consalvo 2006), influenced by localization processes (Mangiron and O'Hagan 2006). Game-related research so far has utilized a cross-cultural perspective to compare and understand the differences and similarities between game markets, production, design, and user experience. In this background, this entry introduces the strands of cross-cultural game research conducted on a macro level, which compare the overall differences and similarities among characteristics of culture of games, gamers, and gameplay on a regional or national level. This entry also discusses current themes and challenges of cross-cultural game studies.

Video Game Market

As the global video game market continues to grow, researchers study the history, expansion, and emergence of the games industry in global and local game markets and explains how the innovation of games and technology influence our contemporary and future culture and society. Dating back to the invention of digital games in the 1950s, the hit and crash of home consoles from the Magnavox Odyssey (1972) to the Atari 2600 (1977), the competition between Nintendo, Sega, and Sony in the early 1980s, joined by Microsoft in 2001, and mobile games proliferating in the present, researchers have been studying the process of how the game markets changes our culture (Wolf 2008, 2012). Looking back at the history of fast-moving video games leads to the realization of how conventional media, entertainment, and technology converge to create a new phenomenon and a new part of culture in our society (Wolf 2008).

Market analysts such as Newzoo (2020) track the developments in the rapidly changing global games market. They provide comparisons of market shares and growth for different regions. Unity Technologies (2020) releases detailed reports focusing on mobile gaming trends. Computer Entertainment Supplier's Association (2020) also delivers annual white papers to report the gaming trends in the world.

Within academia, Johns (2006) closely studies and compares the expansion of hardware and software production networks of game markets, focusing on three supra-regional sections, North America, Europe, and Asia-Pacific. Ip (2008) investigates the games market chronologically, to see how game titles and platforms created in different cultures evolved through convergence of technology and content. However, as Šisler et al. (2017) state, current research on games and focuses on particular regions, while smaller regions are ignored. As the games market further globalizes, partially through online and smartphone technologies, there are needs to systematically analyze differences and similarities in game markets from a broader perspective to understand how games and their meaning change in our globalizing society.

Video Game Industry and Production

Studies on game production, industry, and cultural influence is one of the earliest themes focused on in cross-cultural games research. As it is a challenge for academics to access information from the games industry (Engström 2019), this field of study sheds light upon how games are designed and developed, how developers are structuralized, and how industry across different regions merge to disseminate games in a different cultures. Previous comparative research heavily focuses on the difference between Eastern and Western game development, especially on the differences between Japan and the West. Compared to Western game design, Aoyama and Izushi (2003) note the pervasiveness of the manga and anime industry in the Japanese games industry. The similarities between Western countries and differences of the Japanese games industry are further studied by comparing the evolution and transition of the video games industry in the USA, the UK, and Japan. Johns (2006) claims that North American and European game companies became closer through internationalization, while Japanese game companies grew isolated, creating games influenced by the manga and anime industry. In contrast, Consalvo (2006) also explores the complex transnational relations between the Japanese and American games industries, arguing that the current (console) video game industry is a hybrid that mixes Japanese and American businesses practices and cultures (Consalvo 2006, p.118).

As studies on globalization and transition of major game industries continue, other researchers argue the importance to study smaller regions of game development. Studying the characteristics of game development in three different regions in the Nordic region, India, and China, Toftedahl et al. (2016) point out that the current understandings of video game development have been associated mostly with Japan and the USA, raising concerns to the standardization of the development practices of video game development and limitations to understand the development process in other regions. This shows one challenge of cross-cultural games research. Therefore, researchers capable of cross-regional and industry-academia collaborative research need to take the lead to conduct cross-cultural game development research in order to show the differences and similarities of global and local game industries, contributing to the next generation of game development.

Game Content

As game developers seek to sell their games globally, the process of adapting products, contents, and services to suit the players in each region plays a major role. Carlson and Corliss (2011) show how cultural differences influence game production and game content. Hence, localization is essential to enable video games to be played in a similar way in different markets (O'Hagan 2009). Arguably, it is important to ensure that players enjoy a game created in another culture in the context of their own culture (Mangiron and O'Hagan 2006). Localization involves making decisions about culturally appropriate images, character designs, translation, gameplay mechanics, the technical nature of software, and negotiation of national regulatory boards (Carlson and Corliss 2011). Case studies on cultural differences focusing on the translation of the original game and its localized version are conducted by O'Hagan and Mangiron (2004) and Mangiron and O'Hagan (2006), arguing that the cultural differences impact the characterization of the

main characters. Carlson and Corliss (2011) provide comprehensive examples of what kind of game contents are altered when media travel across national borders, for example how game designers consider to create a generic character instead of a specific one, alter the speed of characters movements to fit cultural preferences, as well as change how blood is displayed in a game due to rating board regulations. Ng (2006) studies how game contents differ between Asian regions, stating that players add new context to games, and also to the culture itself, by consuming and hybridizing with other popular culture.

Player Behavior and Experience

Analyzing the interaction of game and player within their respective contexts has been a central task of game studies (Mäyrä 2008). In cross-cultural games research, researchers have been analyzing the difference of users' playstyles, their perception of games. Game user related studies can be sorted by two axes of 1) research methods, that is, qualitative or quantitative and 2) target regions, that is, Asia-West or Northern America-Western European, with the exception of a study on game culture and players in the Middle East.

In quantitative studies, large-scale surveys are conducted and statistically analyzed. Bialas et al. (2014) examine the playstyles of users in eight different Western countries (Australia, Canada, Finland, Germany, the Netherlands, Sweden, the United Kingdom, and the United States) playing Battlefield 3 with statistical ANOVA tests. Ćwil and Howe (2020) combine statistical tests of chi-square, correlation, and MANOVA to identify differences of gamer identities between players in the USA and Poland. Researchers also designed itemized behavior measurements of video game players and test the measurements' validity among different cultures. Koban and Bowman (2020) utilize a five-factor Video Game Demand Scale (VGDS) to measure demands of video games players in Germany based on the results of measurements in the USA. Kahn et al. (2015) propose a new scale to examine player motivation of American and Chinese participants. Researchers have also investigated behavior focusing on online resources. Šisler et al. (2017) focus on user behavior through social networks, analyzing what fans liked on Facebook, based on an original method of Normalized Social Distance, calculating the distances between various social groups. Zagal and Tomuro (2013) compare Japanese and American user reviews by utilizing statistics and natural language processing. On the other hand, qualitative research investigated players' experiences more closely by analyzing player data through text analyses. For example, Brückner et al. (2019) utilize a Grounded Theory Approach to compare German and Japanese professional and user reviews to identify differences between German and Japanese player.

In terms of regions, cross-cultural research studies heavily involve participants in the USA and Germany, followed by other countries. As Šisler et al. (2017) mention, few research projects concentrate on studying game cultures in Eastern Europe or the Middle East. As such, many possibilities to comparative user studies across different cultures and regions are open and researchers should unite as well as systemize their methods to exhaustively define the differences and similarities among video game players.

Summary

Cross-cultural game studies aim to clarify and compare differences and similarities of games, game markets, game production and design, as well as the meaning and perception on games by game designers and players across two or more cultures on a regional or national level. Culture in game studies is understood as games as cultural artifacts or as parts of subcultures, consisting of a shared way of thinking, behavior, values, language, belief, and gaming practices among specific groups or individuals. Methods utilized in such cross-cultural studies include qualitative analyses of case studies, literature reviews,

interviews, and text analysis, as well as quantitative methods of surveys and statistical tests, network analysis, and natural language processing. Previous cross-cultural game studies mainly focus on the major fields of game markets, game production and design, game content, and player behavior as well as game and player interaction. However, more close analysis on granular fields is yet to be conducted, such as the game market of mobile games and application platforms, regulations, the role of game designers, game mechanisms, detailed analysis of game content, and player perception. Moreover, most studies have the tendency to compare the regions of the West and Asia or the USA and Japan to be in particular; however in this global era, where cultures diversely cross with one another, researchers should aim to study and compare regions on individual levels, to seek the transition and mixture of games and their surroundings. Such cross-cultural game studies lead to clarifying the changes of our contemporary understanding of culture in the globalized and digitized world.

Cross-References

► Games and the Magic Circle

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Cross-cultural Studies

▶ Cross-cultural Game Studies

Cross-culturalism

▶ Diversity in Gaming and the Metaverse

Crossplatform

▶ Redesigning Games for New Interfaces and Platforms

Crowd Animation

▶ Crowd Simulation

Crowd Evacuation

▶ Crowd Evacuation Using Simulation Techniques

Crowd Evacuation Using Simulation Techniques

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Synonyms

Crowd evacuation; Crowd simulation; Macroscopic simulation; Microscopic simulation; Virtual environments

Definitions

Crowd Evacuation Simulation: Using simulation techniques to simulate the motion of crowds in evacuation in virtual environments.

Introduction

Crowd evacuation is important in building design, road infrastructure design, and city planning. A wide range of techniques have been proposed for crowd evacuation. The major aims of the studies on crowd evacuation include: (1) simulating the individual and crowd behaviors, (2) identifying the potential problems of building structures, (3) the effects of obstacles and exits, (4) optimal route computation. In an emergency evacuation, uncontrolled actions are observable in a massive crowd due to the influences of individuals. However, there are ethical issues to perform real life experiments. Therefore, using mathematical models and computer simulations are essential in studying crowd evacuation. The major goal of crowd evacuation simulation is that we would like to find the appropriate solutions to reduce fatality in emergency evacuation.

The organization of the rest of this chapter is as follows. In the beginning, we present crowd behavior analysis. Then crowd simulation techniques are presented, including microscopic, macroscopic, data-driven, and hybrid. After that we present the methods based on psychological factors and multi-cues. The crowd simulation techniques can be integrated into a crowd evacuation system to simulate the interaction among individuals and crowds. The following topics are route computation and crowd evacuation techniques. Finally, we conclude this chapter and highlight future research directions.

Crowd Behavior Analysis

Crowd behaviors (Sakour and Huosheng 2017) can be classified into three types: (1) individual, (2) interactions between individuals, and (3) crowd.

1. Individuals can make a good decision or bad decision in escaping from dangerous regions. They may be panic if the situation is out of control. Experienced individuals can calm down and help others.
2. Interactions between individuals: Inexperienced individuals may follow others even though the others may make a wrong decision. Panic individuals may need the help from others to calm down. Individuals may share ideas with each other to build up their own cognitive map.
3. Crowd: A crowd consists of individuals. Thus, a crowd may increase its density as more individuals join it. However, a higher risk level may be caused due to a degrading comfort level of the individuals.

A successful crowd evacuation technique should capture the essential behaviors of individuals and crowds. We can model crowds, groups, and individuals for scripted, reactive, and guided behaviors (Musse and Thalmann 2001).

Crowd Simulation

Crowd simulation techniques can be classified into macroscopic, microscopic, data-driven and hybrid.

Macroscopic Crowd Simulation

The macroscopic techniques focus on the aggregate behaviors of crowds, evaluation of building structures and performance. The computation cost is relatively lower than the microscopic techniques. In macroscopic crowd simulation, the individuals are grouped together. There are no interactions between individuals in the same group. The motion of pedestrians can be modeled as a kind of fluid.

We can derive a nonlinear, time-dependent equations for pedestrian flow based on three hypotheses (Hughes 2002) as follows:

1. *Hypothesis 1: The speed of pedestrians of a single type in multiple type flow is determined by the function f(ρ) but where ρ is the total density rather than the density of a single pedestrian type.*
2. *Hypothesis 2: A potential field exists for each pedestrian type such that pedestrians move at right angles to lines of constant potential.*
3. *Hypothesis 3: Pedestrians seek the path that minimizes their (estimated) travel time, but temper this behavior to avoid extremely high densities.*

The pedestrians are grouped into different types. Furthermore, The different groups make their way to one of a finite number of objectives. Let ρ_i be the density of pedestrians of particular type i. The total density is $\rho = \sum_{i=1}^{N} \rho_i$, where N is the number of pedestrian types. Then the flow of a particular type i of pedestrians is $\rho_i f_i(\rho)$, where $f_i(\rho)$ is a specified function of total pedestrian density for pedestrians of type i. Assume that φ_i is the potential for type i of pedestrians moving over the (x, y) floor plane. Denote $g(\rho)$ as the factor related to the discomfort of the crowd at a given density, and (x, y, t) denotes the horizontal space and time coordinates. For each type i of pedestrians, the governing equations are as follows:

$$-\frac{\partial \rho_i}{\partial t} + \frac{\partial}{\partial x}\left(\rho_i g(\rho) f_i^2 \frac{\partial \phi_i}{\partial x}\right) + \frac{\partial}{\partial x} \times \left(\rho_i g(\rho) f_i^2(\rho) \frac{\partial \phi_i}{\partial x}\right) = 0 \quad (1)$$

and

$$g(\rho) f_i(\rho) = \frac{1}{\sqrt{\left(\frac{\partial \phi_i}{\partial x}\right)^2 + \left(\frac{\partial \phi_i}{\partial y}\right)}}, i = 1, \cdots, N. \quad (2)$$

One possible choice for $f_i(\rho)$ is that $f_i(\rho)$ is linear in ρ, such as $f_i(\rho) = \beta_i(A - B\rho)$, $i = 1, \cdots, N$. Here, β_i, A, B should be selected appropriately.

A crowd of various types of pedestrians walk toward different objectives or with various speed relationships (Hughes 2003), which are not observed in a classical fluid. The shear force between the pedestrians and ground underneath should be considered.

Microscopic Crowd Simulation

In microscopic crowd simulation, a crowd is treated as a set of particles (or agents). Each agent has its own attributes, including position, velocity, destination, and psychological factors. Furthermore, agents can have interactions among each other. Although the computation cost is relatively higher than macroscopic techniques, the detailed simulation result can be achieved such as panicked individuals.

The simulation space for simulating crowd can be continuous or discrete. In a continuous space, the positions of agents are determined by their current positions and velocities. However, in a discrete space, the simulation space is discretized into a grid and the agents can move only to their neighboring cells. We give examples for these two simulation spaces as follows.

For a continuous space, the new position $\mathbf{p}(t + \Delta t)$ of an agent is updated based on its current position $\mathbf{p}(t)$, velocity $\mathbf{v}(t)$, and time step size Δt, i.e.,

$$\mathbf{p}(t+\Delta t) = \mathbf{p}(t) + \mathbf{v}(t)\Delta t, \tag{3}$$

where t is the current time. The velocity of the agent is affected by factors such as the velocities of neighboring agents, crowd density, and obstacles.

For a discrete space, an agent can jump to a position of a set of fixed positions. Cellular automata are a popular class of discrete models. In a cellular automaton model, it has a grid of regular cells and there is at most one agent at a grid cell at a time. An agent can move from its current grid cell to a neighboring grid cell within a simulation step. Thus, for a regular grid with square cells, there are at most eight neighboring cells for one grid cell.

Discrete Techniques. We use a theatre to illustrate this kind of techniques. The space of the theatre is discretized as a regular grid with square cells. We can construct a floor field by assigning higher probability to aisle regions than seat regions in a theatre (Yang et al. 2010). At an exit area, an information board shows the real time information (e.g., exit density) to the agents to aid them make movement decision. A grid cell dimension is 0.5 m × 0.5 m and it has a total attraction value which is used for computing a probability of an agent to move to it. An agent has a higher chance to move to a neighboring cell with higher total attractive value. The total attraction value of a cell (i, j) is computed as

$$N_{ij} = e^{k_s \times (S_1 + S_2) + k_r \times R + k_d \times D}, \tag{4}$$

where S_1 is the attraction of exit position, S_2 is the attraction of aisle region; R is the repulsive force between agents or between agents and obstacles; D is the influence factor of neighboring agents (due to psychology); k_s, k_d, k_d are the weights for setting the dominant roles of the parameters. R is a non-positive value and D is a non-negative value. Thus, R and D play a negative and positive effect for choosing the cell, respectively. The transition probability to cell (i, j) is

$$p_{ij} = \frac{N_{ij}}{\sum_{(k,\ell)\in G(i,j)} N_{k\ell} \times (1 - n_{k\ell}) \times w_{k\ell}}, \tag{5}$$

where $G(i, j)$ is the set of neighboring cells of (i, j); $n_{k\ell}$ and $w_{k\ell}$ indicate whether the grid cell (k, ℓ) is occupied or there is an obstacle, respectively.

We can combine cellular automata with game theory to perform crowd evacuation (Zheng and Cheng 2011). The main idea is to apply game theory for determining the movement directions of agents. The agents may consider to cooperate or adopt a competitive manner while they evacuate. The following three results are obtained:

1. A longer evacuation time is required and also the frequency of cooperation reduces for higher degree of emergency.
2. Hyper-rationality inhibits cooperation and delays evacuation times, which may lead to crowd disaster.
3. The frequency of cooperation increases for higher degree of imitation among evacuees but also leads to longer evacuation times.

Continuous Techniques. Helbing and Molnar (1995) proposed a force-based model to simulate the behaviors of pedestrians. The surrounding environment and agents exert forces on an agent. The main idea is to compute the total force on an agent. The forces should be considered as influences of the surrounding objects to the agent. We consider that the net force exerting on an agent is **f**. Then the velocity is updated as

$$\mathbf{v}(t+\Delta t) = \mathbf{v} + \frac{\mathbf{f}}{m}\Delta t, \tag{6}$$

where m is the mass of the agent. To determine the velocities of the agents, we can also compute feasible movement directions of agents based on reciprocal velocity obstacles (Van den Berg et al. 2008). The possible movement direction of an agent is computed based on the positions and velocities of the other agents. The feasible direction is picked for avoiding collisions. Furthermore, a collision prediction scheme can be performed to evaluate the possible future collisions of each agent (Karamouzas et al. 2009). Each agent adapts a new route as early as possible in order to minimize the influence of others. In

general, the agent avoids collision with another agent if they may collide in the earliest contact time. The result indicates that the approach leads to shorter and less curved paths.

To achieve biomechanically energy-efficient and collision-free trajectory, we can apply the principle of the least effort to determine the velocities of the agents (Guy et al. 2010). The instantaneous power (P) spent by a walking agent is computed as

$$P = e_s + e_w \|\mathbf{v}\|^2, \tag{7}$$

where $\mathbf{v}$ is the instantaneous velocity, and e_s (measured in *J/Kg/s*) and e_w (measured in *Js/Kg/m*^{2}) are constant. Assume that the mass of the agent is m. The total consumed metabolic energy of the agent while walking along a path is computed as

$$E = m \int \left(e_s + e_w \|\mathbf{v}\|^2 \right) dt. \tag{8}$$

The function E is the subject to be minimized to obtain the path of the agent.

To implement the concept about "right of way," we can assign agents of different priorities (Curtis et al. 2013). The agents with lower priority give way to those with higher priority. This is crucial at narrow regions. If there is no "right of way" mechanism, the agents may block at a narrow passage.

It is efficient to compute the local views of agents to determine the movement of the agents (Fu-Shun Li and Sai-Keung Wong 2016). Each agent has the local view of its neighborhood region and it picks the feasible direction that costs the least effort in term of the turning direction of the agent. Furthermore, the speed of agents is also affected by the local density. For higher crowd density, the speed of an agent is slower. Conversely, if the crowd density is low, the agent can move at its desired speed. The agents can also follow some guidance paths to move. A navigation field can be constructed based on the guidance paths. Each cell of the navigation field has a movement direction and the agent at that cell follows the direction to move. The navigation field can guide a large amount of agents to move to a common destination (Tsung-Yu Tsai et al. 2017). However, if the guidance paths intersect with each other or congestion occurs, we can adjust them by applying particle swarm optimization to achieve better traveling time of the agents (Wong et al. 2015). A fitness function is used to evaluate the quality of the guidance paths. The fitness function for a finite generation period is constructed as follows. All the agents should move to their destinations before the simulation process is terminated. Let $\widehat{N}_G$ be the number of agents not reaching the destination before the simulation is finished. Denote a particle position $\mathbf{x}$ (i.e., a guidance path). Then the fitness function is as follows:

$$F_1(\mathbf{x}) = B\left(\widehat{N}_G\right) * \left(\overline{T} + \alpha \overline{S}\right), \tag{9}$$

where $\overline{S} = \frac{\overline{\ell}}{\overline{s}} \frac{\overline{T}}{\Delta t}$, $\overline{T}$ is the average traveling time, $\overline{\ell}$ is the average interaction distance of agents, $\overline{s}$ is the average desired speed of agents, and α is a constant. $\overline{S}$ is the average extra traveling time for all agents. We would like to adjust the guidance path so that all the agents should reach the destination. Therefore, we set $B\left(\widehat{N}_G\right) = 1$ for $\widehat{N}_G = 0$; and $B\left(\widehat{N}_G\right) = 1 + \widehat{N}_G$ for $\widehat{N}_G \geq 1$. The term $\frac{\overline{\ell}}{\overline{s}}$ represents the extra average traveling time of agents per simulation time step due to collision resolution for agents. The term $\frac{\overline{T}}{\Delta t}$ is the average simulation time steps for agents to move to their destinations. The guidance paths are adjusted iteratively until the fitness value reaches a minimum value (Wong et al. 2015).

Data-Driven and Hybrid Techniques

To calibrate crowd models and group models (Kang Hoon Lee et al. 2007), we can adopt the evolutionary optimization to compute parameters from real videos (Johansson et al. 2007). To achieve better calibration results, we can classify the types of crowd based on steering contexts (e.g., groups crossing and chaos) (Boatright et al. 2015). In this way, we can capture the main characteristics of crowds in each steering context. Based on the characteristics of a steering context for a crowd, the best crowd-simulation technique

can be employed to simulate the crowd. Furthermore, we can measure the density of a crowd to evaluate the similarity between simulation results and real crowd motion in videos (Lerner et al. 2009). The density measure takes into account the local crowd densities surrounding a subject agent. Based on the density measure, we can compute similarity scores for the simulation results and then adjust the calibrated parameters.

Psychological and Multi-Cue Methods

To achieve realistic simulation of high-density crowd, we should combine physical force; agent personalities; and psychological, physiological, and geometrical rules to simulate the local motion of autonomous agents (Pelechano et al. 2007). Furthermore, to handle a large amount of heterogenous agents, we can adopt a multi-agent paradigm in a distributed simulator (Dimakis et al. 2009). Psychological parameters in crowd models make crowds exhibit various personalities and emotions (Durupınar et al. 2016). A virtual agent consists of features that determine cognitive, perceptual, and psychological characteristics. The agents react according to the interaction between the features and environment stimuli. We can integrate different cues including sound perception, multi-sense attention, and understanding of environment semantics, to enhance the realism of crowd (Kapadia et al. 2015).

Evacuation Route Computation

There are mathematical models to compute optimal routes (Hamacher and Tjandra 2002). An environment is represented as a graph which consists of a set of nodes and a set of edges. The nodes and edges are the intersections and roads of the environment. The models require the input of the movement speed of a crowd and road capacities.

To evaluate whether a building is well designed, we can compute the travel time of a crowd (Thompson and Marchant 1995). The quality of an exit assigned to an agent can be evaluated based on earliest arrival flows, maximum flows, and minimum cost flows (Dressler et al. 2010). To make the problem tractable, the methods based on cellular automata can be adopted. Furthermore, controlled dynamic exit signs can be employed for evacuation routes (Desmet and Gelenbe 2014). To compute evacuation routes for three-dimensional networks, we can employ the pseudo-polynomial-time dynamic programming algorithm (Tang et al. 2014).

For evenly distributed agents in an area, we can compute evacuation routes by using the genetic algorithm (Abdelghany et al. 2014). Furthermore, we can apply an evolutionary algorithm to compute the best region assignment that describes how agents in regions are assigned to exits of a building or an open area (Jinghui Zhong et al. 2015). A particle encodes the region assignment and the subregions are encoded as chromes. Mutation and crossover are performed to update the particles based on the result obtained from a cellular automata-based simulation.

An alternative way to compute evacuation routes is to apply agent-based simulation. It is applicable to an environment which can be represented as a road network and a set of obstacles (Sai-Keung Wong et al. 2016, 2017). Agents move along the roads. Along each road, there is a division point which divides the agents on the road into two groups moving in the opposite directions. If the agents move to a junction, they are split into smaller groups and move along the subsequent road segments. The approach computes the division points such that the agents around the division points have similar average evacuation times.

Crowd Evacuation and Building Design

There are a variety of concerns for crowd evacuation. There can be agents of different kinds, such as children, parent, and authorities (Tsai et al. 2011). It is shown that it is effective for a few leaders guiding evacuees to safety regions (Pelechano and Badler 2006). There may be a negative impact if there were too many leaders (Yi Ma et al. 2016). Furthermore, the evacuation strategies should depend on the types of interaction, grouping restrictions, and environment factors (e.g., hazardous areas) (Rodriguez and Amato 2010). Members of the same group should remain

within a predefined distance of others. The members can help each other. Agents may have various degree of knowledge about the environment.

We can adopt appropriate methods to perform evacuation. To perform evacuation in buildings caused by fire, we can adopt dynamic network flows (Hadzic et al. 2011). Regions which are not reachable are removed from the graph. The effects of temperature, spread of smoke speed, and CO (carbon oxide) in fire scenes should also evaluated (Hai-Rong Wang et al. 2014). People should avoid congestion and move to large space. Furthermore, due to guidance signs, people may move together. Thus the movement speed should be carefully monitored to avoid congestion.

To guide the design of a building, we can evaluate the effects of the placement of pillars and doors (Berseth et al. 2015). Let **p** be the set of parameters of a scene configuration. A crowd flow for a specific scenario with parameterization **p** is defined as

$$f(\mathbf{p}) = \frac{|A_c|}{t_{avg}}, \tag{10}$$

where, $t_{avg} = \frac{\sum_{a \in A} t_a}{|A|}$, $|A_c|$ is the destination, t_a is the time taken by agent a to reach the destination, t_{avg} is the average completion time of agents, $|A|$ is the cardinality of set A. The goal of the study was to find **p** which minimizes $f(\mathbf{p})$. The local navigation abilities of the agents affected the results for different kinds of steering techniques. Hence, evacuation techniques based on statistical analysis are highly demanded. Bidirectional traffic patterns are greatly affected by door widths.

Summary

This chapter covers a variety of simulation techniques for crowd evacuation. There are two categories of crowd simulation: macroscopic and microscopic. Macroscopic-based techniques are useful in computing the global behaviors of crowds. To model the individual behaviors and interactions between individuals, microscopic-based techniques should be employed. Hybrid-based techniques are devised from the microscopic and macroscopic techniques. Data-driven techniques can be employed to calibrate the parameters of various crowd-simulation techniques. Route-computation techniques are also crucial. The best routes can be transmitted to devices of people via wireless communication, such as mobile phones (Inoue et al. 2008).

It would be compelling to improve the overall coordination opportunity and evacuation result via cooperation of individuals. Efficient and accurate prediction methods should be developed to prevent disaster from occurring. Due to ethical issues, Sadiyoko et al. (2012) modeled the psychological behaviors of human based on a psychological dynamic model in order to understand how people interact with each other. The models of psychological behaviors can be applied to robots. For example, the emergence of chaos observed in a simulation result of robots can be useful in predicting when a real crowd will occur with the same chaos. Consequently, the chaos for human could be avoided.

Cross-References

▶ Crowd Simulation

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Crowd Simulation

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Synonyms

Crowd animation

Definition

Process of simulating the movement and/or the behavior of a large number of entities or characters.

Introduction

Computer-generated crowds of virtual humans gain a lot of attention these years. Applications are multiple. Accurate crowd simulation is required for risks and evacuations planning. The entertainment industry is demanding of realistic-looking crowd of virtual characters in order to create amazing scenes in movies, commercials, or video games. Believable virtual crowds are the key of success for virtual therapies treating agoraphobia. Real-time 3D crowds could populate virtual cities and virtual worlds can be found on the Internet.

Realistic-looking, believable-behaving, and real-time rendered virtual crowds are challenging. At the individual scale, virtual agent must look realistic, i.e., the 3D models are textured and lighted. They are goal-directed behaving. People don't walk in the streets freely, i.e., going in a random direction each time they encounter an obstacle. Usually they walk with a goal in mind: going to work, shopping. At the crowd level, each virtual character should be unique. Except if you are surrounded by pairs of twins dressed similarly, in real life everybody has different morphology and clothes. Crowd dynamics should be respected. Virtual characters avoid each other to not collide. Flows are created naturally in a dense crowd. Another important aspect of crowd is the number of virtual characters. One can start speaking of crowd if at least one hundred agents are rendered. Massive crowds can count several thousands of characters. Real time adds the constraint that virtual characters are simulated, animated, and rendered at frame rates that allow user interactions.

Most approaches are application specific, focusing on different aspects of the collective behavior, using different modeling techniques. Employed techniques range from those that do not distinguish individuals such as flow and network models in some of the evacuation simulations, to those that represent each individual as being controlled by more or less complex rules based on physical laws, chaos equations, or behavioral models in training systems or sociological simulations.

Historic Background

Human beings are arguably the most complex known creatures; therefore, they are also the most complex creatures to simulate. A behavioral animation of human (and humanoid) crowds is based on foundations of group

simulations of much more simple entities, notably flocks of birds (Reynolds 1987) and schools of fish (Tu and Terzopoulos 1994). The first procedural animation of flocks of virtual birds was shown in the movie by Amkraut, Girard, and Karl called *Eurhythmy*, for which the first concept was presented at the Electronic Theater at SIGGRAPH in 1985. In his pioneer work, Reynolds (1987) described distributed behavioral model for simulating aggregate motion of a flock of birds. Brogan and Hodgins (1997) simulated group behaviors for systems with significant dynamics. Bouvier and Guilloteau (1996) presented a crowd simulation in immersive space management and a new approach of particle systems as a generic model for simulations of dynamic systems. Musse and Thalmann (2001) presented a hierarchical model for real-time simulation of virtual human crowds. Their model is based on groups, instead of individuals: groups are more intelligent structures, where individuals follow the groups' specification. Groups can be controlled with different levels of autonomy: guided crowds follow orders given by the user in runtime; programmed crowds follow a scripted behavior; and autonomous crowds use events and reactions to create more complex behaviors. O'Sullivan et al. (2002) described a simulation of crowds and groups with level of details for geometry, motion, and behavior. Decision systems are generally applied to simple reactive behaviors such as collision avoidance because of the computational cost of implementing existing rational models with a crowd of virtual people.

Variety

To generate thousands of individuals, a naive approach is to design as many humans as there are people in the crowd. Obviously, such an approach is impossible, since it would require armies of designers and an infinite memory. The common and more reasonable approach is to use human templates. A human template is a virtual human defined by its skeleton, its mesh, which is skinned to the skeleton, and its set of textures. To create large crowds, a small group of human templates are instantiated several times. For each instance, one texture is randomly chosen within the template's available set. Then, color and shape variety techniques are applied so that instances of a same template and using the same texture are still different.

Previous work on color variety is based on the idea of dividing a human template into several body parts, identified by specific intensities in the alpha channel of the template texture. At runtime, each body part of each character is assigned a color in order to modulate the texture. Although these methods offer nice results from a reasonable distance, they produce sharp transitions between body parts.

For large crowds, a common approach consists in modifying separately the height of the human body and its shape. The height of a human template can be modified by scaling its skeleton (Fig. 1). For each new skeleton, a global scale factor is randomly chosen within the given range. Then, the associated new scale for each of its bones is deduced. Short/tall skeletons mixed with broad/narrow shoulders are thus created. The skin of the various skeletons also needs adaptation. Each vertex of the original template is displaced by each joint that influences it.

Crowd Simulation, Fig. 1 Changing the height

For the shape, the human mesh is modified using three steps: (1) An area called FatMap (see Fig. 2) is automatically painted on each individual; when the creation of the FatMap is complete, the grayscale values at each texel are used to automatically infer one value for each vertex of the template's mesh. Each of these values, called a fatWeight, is attached to the vertex as an additional attribute. (2) It is computed in the direction the vertices are moved when scaled; for this, we compute the scaling direction of each vertex as the weighted normal of the bones influencing it. (3) Once the direction of the body scaling is computed for each vertex, the actual scaling can take place. The extent to which we scale the body is defined by a fatScale, randomly chosen within a predefined range.

Crowd Simulation, Fig. 2 FatMaps – *Dark* areas represent regions more influenced by fat or muscles modification, while *lighter* parts are less modified

Accessories

Accessorizing crowds offers a simple and efficient alternative to costly human template modeling. Accessories are small meshes representing elements that can easily be added to the human template original mesh. Their range is considerable, from subtle details, like watches, jewelry, or glasses, to larger items, such as hats, wigs, or backpacks, as illustrated in Fig. 3. Distributing accessories to a large crowd of a few human templates varies the shape of each instance and thus makes it unique. We can distinguish three types of accessories.

Crowd Simulation, Fig. 3 Population with accessories: bags, hats, glasses

The first group of accessories does not necessitate any particular modification of the animation clips played. They simply need to be correctly "placed" on a virtual human. Each accessory can be represented as a simple mesh, independent from any virtual human. First, let us lay the problem for a single character. The issue is to render the accessory at the correct position and orientation, accordingly to the movements of the character.

The second group of accessories we have identified is the one that requires slight modifications of the animation sequences played, e.g., the hand close to the ear to make a phone call or a hindered arm sway due to carrying a heavy bag. Concerning the rendering of the accessory, we still keep the idea of attaching it to a specific joint of the virtual human. The additional difficulty is the modification of the animation clips to make the action realistic. If we want a virtual human to carry a bag for instance, the animation modifications are limited to the arm sway and maybe a slight bend of the spine to counterweight the bag. If it is a cell phone accessory that we want to add, we need to keep the hand of the character close to its ear and avoid any collision over the whole locomotion cycle.

The third category of accessories is the one which needs a specific animation; we can consider in this category handicapped people using crutches, skating, and scooter. We may consider accessories that have their motion but linked to the motion of the pedestrian like: a wheelbarrow, a caddy. Accessories may also have their own animation like a dog with a lash. Another category of accessories are the ones requiring more than one person to carry them, for example, furniture.

Figure 3 shows examples of accessories.

Animation Variety

A second important factor, although less paramount is their animation. If they all perform the same animation, the results are not realistic enough. We can consider three techniques to vary the animation of characters while remaining in the domain of navigating crowds, i.e., working with locomotion animations:

1. Variety can be introduced in the animation by generating a large amount of locomotion cycles (walking and running) and idle cycles (like standing, talking, sitting, etc.) that we morphologically adapt for each template. For locomotion clips, walk and run cycles can be generated from a locomotion engine based on motion capture data.
2. Precomputed animation cycles can be augmented with upper body variations, like having a hand on the hip or in a pocket.
3. Finally, procedural modifications can be applied at runtime on locomotion animations to allow crowds to wear complex accessories as mentioned earlier.

The principal component analysis (PCA) method is often used to represent the motion capture data in a new, smaller space. As the first PCs (principal components) contain the most variance of the data, an original methodology is used to extract essential parameters of a motion. This method decomposes the PCA in a hierarchical structure of sub-PCA spaces. At each level of the hierarchy, an important parameter of a motion is extracted and a related function is elaborated, allowing not only motion interpolation but also extrapolation. Figure 4 shows an example of PCA-based locomotion.

Path Planning and Navigation

Path planning is an important and challenging task in crowd simulation, which helps each agent to find the path to its individual goal. The path planning problem has been widely explored by the robotics community. Although the multiple-agent path planning has been addressed for cooperative tasks of multiple robots, it is still a challenge to solve the path planning problem for large crowds in real time, especially for large-scale crowds. Because the methods used for robots are usually exponential in the number of robots,

Crowd Simulation, Fig. 4 PCA-based walking models

which are too expensive to be adopted in crowd simulation.

Four types of methods are popular for path planning and navigation:

1. **Social force models**. Helbing's social force model (Helbing et al. 2000) is one of the most influential models in agent-based motion planning. This model considers each agent as a particle subject to long-ranged forces induced by the social behavior of individuals. The movement of agents can be described with a main function which determines the physical and social forces, similar to Newtonian mechanics. The social force model is capable of describing the self-organization of several observed collective effects of pedestrian behavior.
2. **Probabilistic roadmaps**. Benefiting from motion planning algorithms in robotics, geometric representation of probabilistic roadmaps (PRM) can also be used for path planning in crowd simulation. PRM was applied to solve the problem of determining a collision-free path between a starting configuration of the robot and a goal configuration.
3. **Visibility graphs**. A visibility graph is used for the path planning for large numbers of virtual agents. The visibility graph connects together vertices of the environment if and only if they see each other. Inspired from Voronoi diagrams, Pettré et al. (2006) presented a novel approach to automatically extract a topology from a scene geometry and handle path planning using a navigation graph. The environment is usually discretized into a fine regular grid in the potential field method.
4. **Potential fields**. The method (e.g., Treuille et al. 2006) produces a potential field from the addition of a static field (goal) and a dynamic field (modeling other people). Each pedestrian then moves against the gradient towards the next suitable position in space (a waypoint) and thus avoids all obstacles.

Collision Avoidance

Except the topological model of the environment and path planning, collision avoidance is another challenging problem to be addressed. The collision avoidance techniques should be efficient enough to prevent a large number of agents from bumping into each other in real time. The greatest difficulty of collision avoidance is from the absence of other agents' current velocities. Furthermore, the agents are not able to communicate to coordinate their navigation. A common solution to this problem is to assume that the other agents are dynamic obstacles whose future

motions are predicted as linear extrapolations of their current velocities. The agent then selects a velocity that avoids collisions with the extrapolated trajectories of other agents. This is the idea of velocity obstacle. Considering the case in which each agent navigates independently without explicit communication with other agents, van den Berg et al. (2008) propose a new concept, the "reciprocal velocity obstacle," which takes into account the reactive behavior of the other agents by implicitly assuming that the other agents make a similar collision avoidance reasoning. This concept can be applied to navigation of hundreds of agents in densely populated environments containing both static and moving obstacles for real-time simulation.

Crowd Behavior

The behavior of people in a crowd is a fascinating subject: crowds can be very calm but also rise to frenzy; they can lead to joy but also to sorrow. It is quite a common idea that people not only behave differently in crowd situations but that they undergo some temporary personality change when they form part of a crowd. Most writers in the field of mass- or crowd psychology agree that the most discriminating property of crowd situations is that normal cultural rules, norms, and organization forms cease to be applicable. For instance, in a panic situation the normal rule of waiting for your turn and the concomitant organization form of the queue are violated and thus become obsolete.

A simple method for describing the crowd behavior is through group interrelationships. Virtual actors only react in the presence of others, e.g., they meet another virtual human, evaluate their own emotional parameters with those of the other one, and, if they are similar, they may walk together. The group parameters are specified by defining the goals (specific positions which each group must reach), number of autonomous virtual humans in the group, and the level of dominance from each group. This is followed by the creation of virtual humans based on the groups' behavior information. The sociological effects modeled in the presented rules are:

- *Grouping* of individuals depending on their interrelationships and the domination effect
- *Polarization and the sharing effects* as the influence of the emotional status and domination parameters
- *Relationship* between autonomous virtual humans and groups

Environment modeling is closely related to behavioral animation. The purpose of the models of the environment is to facilitate simulation of entities dwelling in their surrounding environments. Believability of virtual creatures can be greatly enhanced if they behave in accordance with their surroundings. To make crowd movements more realistic, the first important step is to identify the main places where many people tend to go, i.e., places where there is a lot of pedestrian traffic. It can be a shopping mall, a park, a circus, etc. Adding meta-information to key places in an environment has been achieved in many different ways.

A recent effort in improving the crowd behavior has been focused on creating groups. In our everyday life, it is rare to observe people in an urban scene walking all by themselves. Indeed, it is easy to notice that pedestrians often evolve in groups of two or more. For this reason, we introduce an additional and optional layer to our motion planning architecture. This layer takes care of creating small groups of people, which try to remain close to each other during simulation. Figure 5 shows an example of crowd.

Crowd Simulation, What's Next

Crowd simulation is generally seen as the process of simulating the movement of a large number of entities or characters, and key issues seem to be path planning and collisions. But huge crowds generally don't walk; 90 % of crowd images on

Crowd Simulation, Fig. 5 Crowd simulation

Google Images show static crowds. Crowds are not only moving, and even when they move, they can run or even swim in a crowded pool. Most path planning algorithms for walking won't work for swimming.

A lot of research has focused on the collective social behavior of people at social gatherings, assemblies, protests, rebellions, concerts, sporting events, and religious ceremonies, but there are very few simulations showing such case studies.

Behaviors are very situation dependent; for example, people in a city generally walk and stop only to watch events or chat with people. Many people in public parks will sit down in the grass or on public seats.

In terms of appearance, research has focused on shape, size, skin color, and accessories. But, we should see more by representing children, babies, old people, and handicapped people. We should also mix people with cars, bicycles, etc.

Currently, individuals in crowds can carry accessories; what we don't see is crowds manipulating objects, open doors, eating, bringing objects from one place to another, and exchanging objects.

There are other scenes we did not see until now in simulations like large restaurants or crowded buses.

Most crowds are composed of people with a goal; but on a Sunday afternoon, many people wander without specific goals.

Natural motivations should be introduced to simulate more complex and realistic situations. For example, in an airport, people should not just check in, go to the security, then the gate, as in most simulations. They should be able to go to restaurants, cafés, shops, and toilets according to their internal motivations. Such models exist for individuals or small groups, but the problem is that it will be extremely CPU intensive to introduce them to large crowds. More details may be found in (Thalmann and Musse 2012).

Cross-References

- ▶ Character Animation Scripting Environment
- ▶ Crowd Evacuation Using Simulation Techniques

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Crowdsourcing, Scientific Games

▶ Games in Science

Crowdsourcing: User-Generated Content

▶ Gamification in Crowdsourcing Applications

Cultural Diversity

▶ Diversity in Gaming and the Metaverse

Cultural Heritage

▶ 3D Game Asset Generation of Historical Architecture Through Photogrammetry
▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums

Cultural Identity

▶ Preserving the Collective Memory and Re-creating Identity Through Animation

Cyber Security

▶ Audio and Facial Recognition CAPTCHAs for Visually Impaired Users

Cybersecurity Attacks

▶ Anti-phishing Attacks in Gamification

Cybersickness

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Synonyms

Simulator sickness

Definitions

Cybersickness is an uncomfortable side effect experienced by users of immersive interfaces commonly used for Virtual Reality. It is associated with symptoms such as nausea, postural instability, disorientation, headaches, eye-strain, and tiredness.

Cybersickness

Cybersickness is a relatively common, unwanted side effect of immersive interfaces that causes a broad range of unpleasant symptoms such as nausea, headaches, disorientation, and tiredness. More serious symptoms, such as postural instability, although less common, can also result from prolonged exposure to virtual interfaces.

Cybersickness is typically experienced by stationary users that perceive that they are moving in a virtual scene. This stationary reality and the associated compelling experience of self-motion is believed to underlie the condition (Webb and Griffin 2003). By contrast, simulator sickness was first found in pilots who underwent extended training in flight simulators that tried to provide a real sense of vehicle movement using motion platforms (Kennedy et al. 1993). It is likely that there are discrepancies between the simulator's actual motion and the expected motion of the virtual vehicle that contribute to simulator sickness.

Cybersickness and simulator sickness share similar symptoms with motion sickness although the conditions are caused by exposure to slightly different situations. Younger children, aged between 4 and 12, are more prone to motion sickness and indeed susceptibility to this condition in childhood can be a good indicator of susceptibility to cybersickness (Golding 1998). Motion sickness can be brought on by travelling in any type of moving vehicle including cars, buses, trains, aircraft, boats, and submarines and may also be induced on an amusement ride, a spinning chair or simply by using a swing at a playground. Astronauts may experience a related form of motion sickness, called "space adaptation syndrome" that occurs in exposure to zero-gravity conditions (Davis et al. 2015).

While there are definite relationships between the symptoms experienced in cybersickness, simulator sickness, and motion sickness, they may provoke slightly different clusters of symptoms that can help differentiate the three conditions (Kennedy et al. 1993). In one of the largest early studies of symptoms, available data from 10 United States Navy flight simulators, using 1,119 pairs of preexposure and postexposure scores from self-reported data on motion sickness symptoms, were analyzed using a series of factor analyses to identify 16 principal symptoms clustered into the three main categories of oculomotor, disorientation, and nausea (Kennedy et al. 1993). The oculomotor cluster includes the symptoms of eyestrain, difficulty focusing, blurred vision, and headache (Kennedy et al. 1993). The disorientation cluster includes dizziness and vertigo, while the nausea cluster includes stomach awareness, increased salivation, and burping (Kennedy et al. 1993). A further dimension of cybersickness related to the "sopite syndrome" has also been characterized, and this includes symptoms of drowsiness, yawning, disengagement, and negative affect (Lawson and Mead 1998).

The actual cause of cybersickness is not known and the underlying physiological mechanisms are uncertain. The three most prominent theories for the cause of cybersickness are postural instability theory, poison theory, and sensory conflict theory (LaViola 2000).

The postural instability theory is based on the idea that the main goal of humans is to maintain postural stability in the environment (Riccio and Thomas 1991). Therefore, prolonged postural instability results in cybersickness symptoms and the longer the instability, the more severe the symptoms are likely to be (LaViola 2000). By contrast, poison theory suggests an evolutionary survival mechanism comes in to play when the user experiences sensory hallucinations consistent with ingesting some type of poison (Bouchard et al. 2011). It is suggested that patterns of visual and vestibular stimuli may trigger motion

sickness by accidentally activating brain sensors for detecting toxins (Treisman 1997).

However, the most longstanding and popular explanation for cybersickness is known as the sensory conflict theory (Cobb et al. 1999; Kolasinski 1995; LaViola 2000). This theory describes the conflicts of two key sensory systems engaged in virtual environments, namely, the visual and vestibular senses (Kolasinski 1995). They provide information about an individual's orientation and perceived motion, and it is the mismatch of these senses that can frequently occur in Virtual Reality. For example, the vestibular system may be telling the individual that their body is stationary, while the visual system is telling them that their body is moving, causing a sensory mismatch (Howarth and Costello 1997). Unfortunately, like the other theories, the sensory conflict theory lacks predictive power in determining how severe the symptoms of cybersickness will be relative to any virtual experience. Furthermore, these various theories still fail to explain why, given identical virtual experiences, some individuals get sick and others do not.

While the underlying mechanisms that cause cybersickness are still not completely understood, there has been more success in identifying some of the factors known to impact on users developing symptoms. These factors are varied and relate to individual differences, variations in the devices being used, the task being performed, and the design of the virtual environment.

Individual factors that impact on cybersickness include age, gender, race, illness, and posture. Children in the 2–12 age range have the greatest susceptibility to cybersickness, and this rapidly decreases from the ages of 12–21 and beyond (Kolasinski 1995). Thus, older people are less susceptible to symptoms. In relation to gender, women have a wider field of view which increases the likelihood of flicker perception and this in turn increases their susceptibility to cybersickness (LaViola 2000). Research has also shown that female hormones can affect susceptibility (Kolasinski 1995). For all users, any underlying illness increases an individual's susceptibility to cybersickness. These physical conditions include, but are not limited to, fatigue, hangovers, and the flu (LaViola 2000).

The ranges of device factors that impact on cybersickness are lag, flicker, calibration, field of view, and general ergonomics. One problem with most stereoscopic displays is known as accommodation-convergence conflict (Durlach and Mavor 1994). In the real world, our eyes converge to look at near objects while also focusing (accommodating) at the same distance on the object. However, in Virtual Reality, while the eyes will still converge to look at a virtual object, the focus needs to be on the plane of the display itself rather than the object. Other characteristics of head-mounted displays that may be relevant are the vertical and horizontal field of view, the resolution, the contrast, the luminance, and color characteristics of the display (Durlach and Mavor 1994).

The refresh rate of the display can also be important factor as any lag in the system can contribute to cybersickness symptoms (LaViola 2000). Lag occurs when there is a delay between an individual's action (e.g., turning a steering wheel) and the system's reaction. Real time graphical displays that can operate at around 50–60 Hz are critical. Efficient tracking of head movements is also critical as people expect their view to change promptly when they move their head. Any errors in accuracy of tracking of head movement can likewise impact on cybersickness. Display flicker, a visible fading between video frames, is also related to visual refresh rate. Flicker is not only distracting but also causes eye fatigue (Kolasinski 1995). Flicker fusion is an important property of the device and is even more critical for wider fields of view as peripheral vision is more sensitive to flicker (LaViola 2000). The perception of flicker is another factor that can also vary between individuals.

Due to differences in physical characteristics, poor system calibration can also increase cybersickness symptoms. For example, interpupillary distance, which is the distance between the centers of the pupils of both eyes, varies between individuals (Kolasinski 1995). As stereoscopic displays require each eye to receive a slightly offset view

of the virtual world, this offset needs to correspond as closely as possible to the users own specific interpupillary distance. As such appropriate calibration is required for each individual. General ergonomic factors also need to be considered when designing immersive systems. For example, heavy and poor fitting headsets can cause physical discomfort, and restricted movement from cables can cause further distractions from the virtual experience (McCauley and Sharkey 1992). Furthermore, head-mounted displays impact on the normal inertia characteristics of the head, generating unusual forces during head movements that can also directly impact on cybersickness (Durlach and Mavor 1994). The posture of the individual, possibly related to the postural instability theory, is also important. For example, sitting is a safer posture for users than standing as this reduces any demand on postural control (Kolasinski 1995).

Cybersickness can also be influenced by the specific task the user is performing in the environment. The main task factors include the level of control the user has and the duration of the task. Participants who have good control in a virtual environment can better predict future motion and are found to be less susceptible to cybersickness. By contrast, users with no control over the virtual environment lack the same level of predictability about the environment and are thus more prone to symptoms (Kolasinski 1995). Longer exposure times to Virtual Reality also increase the likelihood and severity of cybersickness and lead to the need for longer adaptation periods. Indeed, using brief exposures to virtual environments is one way to improve the speed of adaptation (Kolasinski 1995; McCauley and Sharkey 1992).

As the illusion of motion is one of the factors that induce cybersickness, the design of the virtual world, in terms of visual complexity and amount of motion associated with the visual stimuli, is also an important factor that might be controlled (So et al. 2001). For example, during the design of virtual experiences, optical flow might be used as a measure the complexity of motion in a stream of video frames (Ali 2013; Beauchemin and Barron 1995). Likewise, a measure such as approximate entropy can be used to provide a general understanding of the complexity of changing scenes in a virtual environment (Smith et al. 2017).

As it stands, cybersickness still provides an obstacle to the wide spread adoption and commercial development of technologies associated with Virtual Reality. Of particular advantage would be better quantitative measures for predicting a user's susceptibility to cybersickness and reliable methods for detecting and measuring symptoms such as the nausea associated with the condition. Most historical studies of cybersickness have relied on subjective self-reporting of the severity of symptom conditions (Ames et al. 2005; Cobb et al. 1999; Dennison et al. 2016; Gianaros et al. 2001; Golding 1998; Kennedy et al. 1993; Nesbitt et al. 2017).

The Pensacola Motion Sickness Questionnaire (Kellogg et al. 1965) based on 27 previously identified issues (Hardacre and Kennedy 1963) is recognized as one of the earliest subjective measures designed for assessing motion sickness (Bouchard et al. 2011). This work led to the development of the Pensacola Diagnostic Index (Graybiel et al. 1968). The Pensacola Diagnostic Index score is calculated by summing an individual's ratings on various scales related to the symptoms of dizziness, headache, warmth, sweating, drowsiness, salivation, and nausea. After a major study analyzing the factors relevant to simulator sickness, an alternative 16-item Simulator Sickness Questionnaire was developed (Kennedy et al. 1992). Another widely used survey instrument is the Nausea Profile (Muth et al. 1996). Like the Simulator Sickness Questionnaire, the Nausea Profile is distinguished from approaches such as the Pensacola Diagnostic Index in that it examines symptoms along multiple dimensions. Another multivariate questionnaire was developed to measure the symptoms associated with the subscales of gastrointestinal, central, peripheral, and sopite-related symptoms (Gianaros et al. 2001). More recently, the Virtual Reality Symptom Questionnaire (Ames et al. 2005) was developed specifically for investigating symptoms that result from Virtual Reality viewing using technology such as head-mounted displays.

Generally, subjective approaches for measuring cybersickness symptoms elicit an individual's ratings on scales that relate to either the propensity to be susceptible to simulator, motion, or cybersickness, or the experience of sickness under provocation conditions. Subjective measurements may be impacted by systematic biases and psychological factors (Jahedi and Méndez 2014), and thus there is a trend to devise more objective measures of cybersickness (Bouchard et al. 2011; Bruck and Watters 2011; Cowings et al. 1986; Gavgani et al. 2017; Kim et al. 2005; Nalivaiko et al. 2015). These objective measures are of particular interest in training domains where independent identification of susceptibility, or affectedness, can assist in maximizing training experiences, minimizing postexposure effects, and optimizing content to reduce provocation.

Objective approaches focus on the measurement of physiological responses to cybersickness (Kim et al. 2005). The key physiological changes include sweating, alterations in gastric myoelectric activity and in cardiac vagal tone, an increase in the delta-power of the EEG, and a rise of plasma vasopressin (Stern et al. 2011). In one study, 16 electrophysiological parameters where collected while subjects navigated a virtual environment (Kim et al. 2005). During this provocation, some parameters increased (gastric tachyarrhythmias, eye blink rate, skin conductance, respiratory sinus arrhythmia, and delta-power of the EEG), while other decreased (heart period, fingertip temperature and photoplethysmographic signal, and EEG beta-power). Of those changes, several (gastric tachyarrhythmias, eye blink rate, respiration rate, respiratory sinus arrhythmia, and heart rate) had significant positive correlation with the subjective score of cybersickness. In a further study, immersion in a virtual environment resulted in an increase of the low-frequency but not high-frequency components of the heart rate variability (Ohyama et al. 2007). In conjunction with the previously mentioned work, this may indicate that cybersickness is associated with an increase of the cardiac sympathetic outflow.

It is less known but well documented that motion sickness causes disturbances in thermoregulation (Nalivaiko et al. 2014) that manifest as dilatation in the cutaneous vascular bed and reduction in thermogenesis; it is quite likely that "cold sweating" is a part of this thermoregulatory response. The dilatation of cutaneous vessels during provocative motion has been confirmed in experimental animals (Ngampramuan et al. 2014) and thus appears to be a cross-species real-time marker of motion sickness (Nalivaiko et al. 2014).

It appears that objective signs of cybersickness resemble those of other types of motion sickness; it is however not known whether subtle differences exist, similar to differences in symptoms between motion sickness, cybersickness, and simulator sickness. In the future, it is likely that both objective and subjective approaches will be used to help design better devices and experiences in Virtual Reality that improve understanding of this complex condition while helping to minimize the commercial impact of cybersickness. Further detail around cybersickness can be found in a recent systematic review (Davis et al. 2014).

Cross-References

- ▶ Perceptual Illusions and Distortions in Virtual Reality
- ▶ Redirected Walking
- ▶ Spatial Perception in Virtual Environments

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Cyberspace

► Diversity in Gaming and the Metaverse

Cyberworld

► Virtual Reality and Robotics

Cyborg

► Virtual Reality and Robotics

D

Dark Side of Gamification

► Gamification Ethics

Dark Souls

► Dark Souls Through the Lens of Essential Experience

Dark Souls III, an Analysis

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Synonyms

Action role-playing game; Adventure game

Definitions

Adventure game = A game genre where the players are motivated by exploration, the unknown, and solving puzzles.

Action role-playing game = a game genre combining elements of both action and role-playing games. Players assume the role of a character in their unique world. Combat is done in real time as opposed to turn-based games.

Dark Souls III Action-Adventure Role-Playing Game

Dark Souls III is an adventure and action role-playing game developed by From Software and published by Bandai Namco. *Dark Souls III* came out in Japan on March 24, 2016, and later to the rest of the world on April 12, 2016. It is both a single and multiplayer game that was released on Xbox One, PlayStation 4, and other consoles with an M rating. *Dark Souls III* is the third game in the *Dark Souls* franchise.

In *Dark Souls III*, the player fights their way through countless enemies as they progress through the game. *Dark Souls III* takes pride in being one of the most difficult games that gamers can find. The gore and character designs heavily aims for an adult audience.

This is a game that has very few cutscenes; instead, the game relies on in-game item descriptions and dialogue with the NPC's to tell the story. *Dark Souls III* is set in the fallen country of Lothric. In the beginning of this world, the only beings in existence were the immortal dragons. After the discovery of fire, multiple types of life began to come out of the darkness.

This started the cycle of fire and darkness. At the start of the game, the players are awakened by

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Dark Souls III, an Analysis, Fig. 1 Character creation also lets players customize almost every aspect of a character

the sound of a bell that is warning that the fire is in danger of going out. This leads them to a building where the fire is located. What they find is that only one of five of the Lords of Cinder remains to keep the fire lit. Their job is to go and defeat the other lords and bring them back to the fire. The Lords of Cinder are Ludleth of Courland, Abyss Watchers, Aldrich the Devourer of Gods, Yhorm the Giant, and Lothric the Younger Prince.

In *Dark Souls III,* the player starts the game in a character creation screen (Fig. 1). Here they choose an origin that gives them stats that are based on the origin. An example of this would be that a knight will have default stats that are suited for melee combat, like strength.

Dark Souls III has bonfires that are placed around the map. These bonfires are lit by walking up to one and lighting them. These bonfires are save points which will reset health and estus flasks. These bonfires also act as a fast travel system to go from one bonfire to another.

The combat in this game is based on figuring out the patterns and attacks the enemies use to dodge, block, or counter their attacks. The health system in the game uses what are called estus flasks. They give portions of health back. Players can collect in game items to increase the number of flasks they have and how much health they will restore. The magic in this game has the same type of system but they are another type of flask called ashen estus flasks. The catch is that the health flasks and magic flasks are connected, meaning that players can only have seven total flasks at once. The ratio of health to magic flasks can be adjusted in-game at the blacksmith.

The stamina system in *Dark Souls III* is set so that as a player runs, stamina will deplete. If one stops running, their stamina will fill back up. Stamina also depletes each time they use a weapon or dodge (Fig. 2). The amount of stamina a player has can be increased by leveling up their stats.

In *Dark Souls III,* when a player dies, they will start to become hollow. The more they die, the more hollow they will become. Hollowing is an effect that will gradually start to lower the max amount of health they will have. This will also start to make their character look more and more decayed. The way they can reverse the effect is to find embers that are scattered around the map.

Dark Souls III, an Analysis, Fig. 2 The picture above is to show the games interface. In the top left corner is the red health bar, blue magic bar, and green stamina bar. In the bottom left corner, there are equipment boxes. Inside these boxes are usable items and weapons will be displayed. The bottom right corner has a counter showing the number of souls collected

Once a player uses one, their health's max level will go back up and their character will look normal again. This state is called being embered. Hollowing also prevents multiplayer. If a player dies, their loot will be dropped where they died. If they die again before returning to collect the loot, they will vanish.

Dark Souls III has a mechanic in the game that limits the amount of items players can have on their person by weight. The less weight players have, the faster their character can move. This is shown to the player in a percentage. If they are below 30% of max weight capacity, they are faster than normal. The normal weight range is between 30 and 70%. At this weight, they are moving at the normal speed of their character. At 70% or higher, the character will slow down drastically. Movement speed and dodging speed will go down and stamina will regenerate slower. If it is over 100%, they will no longer be able to run or dodge. The game calls this state being overburdened. A player can increase their max carrying capacity by leveling their stats.

In this game, the currency, called souls, is used to buy equipment or upgrades. Souls are dropped by enemies. These are traded in to different NPC's to upgrade stats or to get new equipment. Souls can also be used to upgrade the equipment that they already have.

To upgrade the equipment, players have to find in-game items that match the specific weapon they are trying to upgrade. Along with these items, players will need a certain amount of souls to upgrade as well. A piece of equipment can be upgraded a total of ten times. Each time the equipment will get stronger but the amount of items they need to upgrade the equipment will also increase.

Dark Souls III has a unique style of multiplayer. There are items in the game that can be used to make a mark on the ground. This mark can be seen by other players in their game if they are in the area. The player will have to go and accept the player so he can join the other player's game. They can put down a red or white mark. A red mark will bring them to another's world as an enemy and a white mark will bring them as an ally. There is a feature where a player can invade another's game. This will make them unable to progress unless the defeat the invaders or they are defeated themselves.

The levels in *Dark Souls III* are designed so that players fight through enemies to clear out the

area and collect all of the items in the area. If players die while clearing the area, the enemies that they killed will respawn. Each level has a boss at the end that they have to beat to continue. There are some optional bosses that do not need to be beaten to continue. These bosses are found in optional levels that branch off from the main levels. As players fight through the levels, the enemies' difficulty increases, as does the number of souls they drop. The items that they drop and the items they can pick up from the world will also increase in value.

Dark Souls III had great public reviews. Gamespot.com rated *Dark Souls III* as an 8/10. PC Gamers rated the game a 94 out of 100. Metacritic rated the game 89 out of 100. *Dark Souls III* has no notable controversies.

There have been many improvements to the franchise since the first game. The second game improved the hollowing system by adding the lowering of the health cap. *Dark Souls III* further improved this system by adding dark sigils. The more sigils a character has, the more the hollowing affects them. *Dark Souls III* is also the first game in the series to introduce the magic bar. In the previous games, spells were limited use and could be restored at a bonfire. The games also had graphic upgrades from game to game. The pictures from top left to right (Fig. 3) show the graphical upgrades.

Dark Souls III, an Analysis, Fig. 3 There are two games made by the same developer that are similar to these games. The first is the game that was released before the original *Dark Souls*, and it is called *Demon Souls*. The next game called *Bloodborne* is also very similar to the *Dark Souls* franchise and was developed by the same developers. *Nioh* and *Lords of the Fallen* are games that are also similar to *Dark Souls III*. These two games are made by different developers and have different plots, but they have the same style of clear an area and then fight a boss gameplay

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Dark Souls RPG Through the Lens of Challenge

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Synonyms

Action RPG; Soulslike

Definition

RPG = A roleplaying game where the player controls the actions of a character in an immersive virtual world.

Dark Souls = An action RPG released in 2011, which has gained infamy in the gaming industry for its high difficulty.

Introduction

Dark Souls is a notoriously difficult video game that alienates most people from trying it. This article explains what makes Dark Souls a good game through the description of its gameplay systems, and how its difficulty makes it a more worthwhile experience.

From Software, the developer of *Dark Souls,* didn't always have the booming success that it has today. It was originally formed in 1986 as a developer for office software, but in 1994 it jumped onto the gaming scene with *King's Field* for the PlayStation*,* a first-person dungeon crawler RPG that saw the player explore dungeons, solve puzzles, and fight monsters. *King's Field* retained the level of difficulty that the *Souls* series would eventually be known for, but a lot of the difficulty came from the bizarre controls and obtuse puzzles. *King's Field* would spawn a few more sequels on PlayStation 1 and 2, but it never had the success that other competing RPGs like the *Final Fantasy* series did (Ciolek 2015).

In 2009, *Demon's Souls* was released to not much fanfare. It was originally only released in Japan, but Western players were able to import it and find a difficult but rewarding experience. This convinced Atlus to publish the game in the West, where it found immediate success. *Demon's Souls* is the first Soulslike game From Software ever released, and many of its gameplay systems would be refined and implemented into *Dark Souls* (Ciolek 2015).

Dark Souls was released in 2011 for the Xbox 360 and PlayStation 3. It received universal acclaim from critics and was cemented as a hallmark of gaming. As of 2022, the *Souls* series has sold 27 million copies (Hannah 2021).

Plot

Making sense of the plot to *Dark Souls* can be a daunting task for newcomers. Aside from the

opening cutscene that plays when the player starts a new playthrough, the game doesn't explain its story very well. Every secret about the game's world and its lore must be found by the player, whether that be through character interactions or by reading item descriptions. This adds a level of immersion unmatched by most other games, as the player is learning with their character, but it's entirely possible to beat the game without understanding the plot.

The player controls the Chosen Undead, an undead warrior prophesized to prolong the Age of Fire by ringing the Bells of Awakening. However, this prophecy is misleading, as many undead have undertaken the pilgrimage and failed. Those that have failed became hollow and lost their sanity. The Chosen Undead is not actually chosen by anyone, rather, it could be said that the Chosen Undead is whoever is able to ring the bells first ("Dark Souls Lore Explained!" 2020).

Gameplay

Dark Souls has combat like most 3D *Zelda* games: the player can attack, dodge, and lock on to enemies, and a lot of time is spent hiding behind a shield. What sets *Dark Souls* apart from *Zelda,* however, is resource management. *Dark Souls* has a stamina bar that drains with nearly every action the player can perform. This includes sprinting, attacking, and dodging. This means that if the player spams the attack button until they run out of stamina, they won't have any stamina left to dodge an incoming attack until the bar refills. Patience, timing, and careful stamina usage are important in order to succeed in *Dark Souls.*

Along the journey, the player will find bonfires. Bonfires act as checkpoints for the player, and allows them to replenish their health, magic, and Estus Flask, a magical healing drink that the player can use a limited number of times before resting at a bonfire. However, bonfires will also respawn all previously defeated enemies except for bosses.

When the player dies, they respawn at the last bonfire they visited and they lose all their souls, which act as both experience points and a currency. The player has one chance to return to the spot where they died in order to retrieve them, but if they die again before that happens, their souls are gone forever.

If the player character was human before they died, they will become hollow. Hollowing will change the player's appearance to that of a zombie and disables the summoning of NPCs or other players for bosses. On the other hand, it also protects the player from invaders, other players with their own copies of *Dark Souls* whose only goal is to kill the player. Depending on the situation, being hollow can be either a detriment or a benefit.

The world of *Dark Souls* is massive, but linear. It wouldn't be inaccurate to compare the structure of the map to that of a Metroidvania, as the player slowly unlocks more of the map as they play, and they have the option to use shortcuts to access different areas quickly. Players can complete certain objectives out of order, but they still must be done in order to beat the game. For example, at the beginning of the game the player is tasked with ringing two bells: first, one in Undead Burg, and then one in Blighttown. Depending on how they start, the player could ring these bells in any order they want, but they must ring both before they can do anything else.

A Reputation for Difficulty of *Dark Souls*

Dark Souls has built up a reputation of being one of the hardest games one could ever beat. Many gamers are intimidated from trying *Dark Souls,* or any other Soulslike games, due to this difficulty. Despite this, the *Souls* series has plenty of devoted fans that sing its praises, and *Dark Souls* is seen as one of the best games ever made.

Dark Souls is not an easy game. It's likely that first-time players will die hundreds of times before they see the ending, so some players may begin to feel frustrated if they are not making progress, which isn't helped by the fact that the player will lose all their souls every time they die. Unless the lost souls were enough for the player to level up, its generally not worth going back for them. It's also recommended to spend all souls before venturing into a new area or fighting a boss.

The game also doesn't always make it clear where players are supposed to go or how certain mechanics work. Progression is linear, especially early on, but it's still possible to miss important items if the player doesn't explore. If the player is confused about where to go next, it might be best to look up the solution online or they might be wandering around for hours.

As the player progresses, they will find enemies with bigger health pools, and they might feel that they are not doing enough damage. There is a blacksmith named Andre at the end of the Undead Parish that will upgrade weapons and armor. While it's possible to beat the game without ever visiting Andre, the player will be weak, and their weapons and armor will eventually break. It is recommended that the player backtracks to this area occasionally to make sure their gear is up to date.

If the player is stuck on a boss, they have the option to summon an NPC or another player, though NPC summon signs are often hidden and there isn't a guarantee other players will be online. If summoning was fruitless, it might be worth grinding or traveling to a different area, if possible.

Reception

Dark Souls is unlike most action RPGs that came before it. It can be ruthlessly difficult sometimes, but the gameplay is tightly designed and balanced in a way where the player won't get stuck if they explore every option they have. The satisfaction of overcoming a difficult area or boss also makes continued play more rewarding than many other action RPGs as well. The experience of playing *Dark Souls* has stuck with many gamers. Keza MacDonald of IGN gave it a 9 out of 10, saying that it was "one of the most thrilling, most fascinating and most completely absorbing experiences in gaming" (MacDonald 2011).

At the 2021 Golden Joystick Awards, *Dark Souls* won the award for Ultimate Game of All Time, beating out many other immensely popular games like *Doom, Minecraft,* and *The Legend of Zelda: Breath of the Wild* (Ammerman 2021).

Cross-References

- ▶ Dark Souls Through the Lens of Essential Experience
- ▶ Dark Souls III, An Analysis

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Dark Souls Through the Lens of Essential Experience

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Synonyms

Dark souls; Essential experience; Player experience

Definition

Lens of essential experience – A critical thought process by applying the concept of player experience in scrutinizing or analyzing a game

Former Disney game designer Jesse Schell stated that every memorable experience has

some key features that define it and make it special (Schell 2015). Without an impactful experience, how would video games be popular mediums of entertainment? The lens of essential experience encourages game designers to create a whole new world, whether familiar or alien, to witness something that its consumers could not find through any other means. We humans experience things every single day, yet some of us still seek video games to fill our inquisitive minds. One exemplification of games that portray excellent player experience is Dark Souls, a third-person action role-playing game developed by FromSoftware and published by Namco Bandai Games in 2011 for PlayStation 3 and Xbox 360. Dark Souls is known for its impossible level of difficulty, but it still managed to become a classic within the gaming community's collections.

Dark Souls answers the three questions for the lens of essential experience: "What experience do I want the player to have?", "What is essential to that experience?", and "How can the game capture that essence?". As stated before, Dark Souls is known for its unbearable difficulty. How could a game so difficult deliver such a memorable experience? It is simple: the value of experiencing the massive world, bosses, and lore helps make this a game to play. These elements are essential to being able to have an impactful experience. The difficulty itself is the most unique experience a person can have; without it, this game would not have been as popular of a game as it is.

The player must learn and observe the world that Dark Souls sets in front of them. The only reason Dark Souls is considered difficult may be because the player is thrown into an unfamiliar environment. Of course, this is not a game that a player can just jump into and expect positive results; it's up to the player to figure out the mechanics, the boss's attack patterns, and the map they are thrown into. The player takes the role of a handcrafted character that they may create themselves. The player has free reign over the character that they assemble; this means the player gets to experience the world around them in a whole new light. Game director and producer Hidetaka Miyazaki modeled various places in the game after real-world locations including the Milan Cathedral in Italy. As the player progresses through this lustrous world, they encounter many challenging bosses as they venture forward to succeed Lord Gwyn to fulfill the prophecy of returning the Lost Soul to the First Flame.

Defeating bosses is the main objective, but the player must first explore each map as well as learn the lore around the areas they encounter. The player virtually gets to undergo this world without limits as it is an open-world game; this means the player gets to experience the game as they please, not being directly pointed in the right directions. In fact, the player is not spoon-fed with the quests they must undertake. The player as a character must decide on how to commence their adventure. There are many different routes the player may take to complete the game. This is an interesting idea as it means that their characters get to adventure forward as they so choose.

Among just experiencing the world alone, they have the option of inviting friends to ally them on their journey or being invaded by enemy players who are also playing the game. Friends enable an even higher level of difficulty because the bosses increase their stats with each new ally. Enemy players all have the objective of killing the player on their adventure. In Dark Souls the player must approach bosses and the world around them with an open mind, learn the patterns of the bosses, and explore alternative pathways around the world all while cooperatively traversing with friends or being attacked by foes.

All these elements of Dark Souls capture the essence of experience. If any one of these attributes had been excluded from the final build of the game, it would not have done as well as it did. The lens of essential experience is an important lens for creating a masterpiece, and Dark Souls clearly shows how, if applied correctly, someone can develop a phenomenal video game.

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Data Baking

▶ Plug-in-Based Asset Compiler Architecture

Data Compiler

▶ Plug-in-Based Asset Compiler Architecture

Data Cooking

▶ Plug-in-Based Asset Compiler Architecture

Data Gloves for Hand and Finger Motion Interactions

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Synonyms

Deafblind communication interfaces; Extended Malossi alphabet; Gesture-based interactions; Hand and finger motion tracking; Motion and posture analysis

Definition

Data gloves are wearable devices with incorporated sensors that allow for motion and posture tracking of the user's hands and fingers. Since direct sensing is employed, there are no environmental restrictions and timely, highly reliable data can be collected. Motion interactions are then implemented through real-time analysis and recognition of the user's hand and finger postures and gestures. The employed nonoptical sensing method is particularly suitable for interactions of deafblind users through an extended Malossi alphabet.

Introduction

The first report of a finger motion tracking data glove (DeFanti and Sandin 1977) appeared in 1977 and was followed by various research efforts and implementations of glove-based input for hand and finger motion digitization (Sturman and Zeltzer 1994; Dipietro et al. 2008). The direct tracking of finger motions pursued by this approach is of particular interest in areas where gloves are considered indispensable. Data gloves can be employed, for example, in medical training, where surgical gloves are mandatory for many medical procedures. For adequate experience, such data gloves should match the physical properties of the surgical gloves and provide very similar touch and feel. To achieve this, novel materials are nowadays specifically designed to meet the requirements of the target application domain. In addition, recent technological advancements are employed for implementing finger motion tracking sensors that blend into the glove fabric and allow for seamless integration.

The early wired glove designs (DeFanti and Sandin 1977) employed embedded optical sensors constructed from light emitters and photocells. The components of the optical sensors were connected by flexible rubber tubes that bended following the motions of the human fingers (Zimmerman 1985). In result, the light reaching the photocells decreased proportionally to the tube bend and thus controlled the output voltage of the photocell. A later method (Harvill et al. 1992) employing optical fibers with an intentionally damaged surface that attenuated the light propagation proportionally to the bend lead to

the construction of more flexible and easier to handle optical sensors. More advanced fiber-optic sensors based on double cladding fiber (Ivanov and Chertoriyskiy 2015) were also employed in high-end gloves such as the Virtual Programming Languages (VPL) Dataglove (Zimmerman et al. 1986).

Capacitive and resistive bend sensors (Neely and Restle 1977) on the other hand were used in consumer-grade products such as the Nintendo Power Glove (Gardner 1989). Note that some bendable resistive sensors for wired gloves were produced by applying conductive inks to a flexible substrate (Langford 1996). However, such bendable sensors tend to produce an asymmetric response since conductive inks on a flexible substrate are more sensitive to expansion than to compression.

Sensing of the bending is often insufficient when high fidelity finger motion tracking and the detection of subtle finger movements are targeted. For this, stretchable sensors employing either capacitive (Hirata et al. 2015; Tairych and Anderson 2019; Glauser et al. 2019) or resistive (Firouzeh and Paik 2015; Sbernini et al. 2016; Lee et al. 2018) technologies appear to be more suitable.

Advanced Carbon Nanotube (CNT) Based Sensors

Rapid-response widely stretchable sensors are indispensable for the detection of the subtle human hand and finger motions. Those are specialized sensors derived from the recent research on the synthesis of vertically aligned ultralong multiwalled carbon nanotubes (CNT) using iron chloride powder (Inoue et al. 2008). The unique process essential for the reliable and cost-effective fabrication of the CNT material embedded in such high-fidelity motion tracking sensors is as follows.

A 2.1-mm long CNT array is first grown by conventional thermal chemical vapor deposition on a quartz surface with a single gas flow of acetylene for 20 min. It is then spun into a yarn, thus converting the three-dimensional array into a horizontally aligned web. Afterward, well-aligned CNT sheets are fabricated by stacking and shrinking the CNT Webs (Inoue et al. 2011).

Experimental CNT strain sensors are manufactured by placing the CNT sheet on a flat and smooth substrate (e.g., glass) in a direction parallel to the stretching direction and impregnating it with elastomeric resin. This process requires a rubber-like elastomeric resin with low elasticity and low-loss properties such as polycarbonate-urethane (PCU) and segmented poly-tetramethylene ether glycol-urethane (PTMGU) to enhance the contraction properties of the substrate (Suzuki et al. 2016).

To further stabilize the contraction behavior of the sensor, an elasticity-assist layer is applied on top of the elastomer resin surrounding the CNT bundle. Since the resistance naturally increases with strain due to the cracking of the CNT sheet network, obtained elasticity can be adjusted by changing the number of layers in the employed CNT sheets. This enables the construction of stretchable sensors with predefined resistance that allows for more accurate motion tracking.

Note that the sensor resistance is proportional to the applied tensile strain that increases with the applied force. The temporal strain changes are closely followed by the variation of the strain sensor resistance that can exceed 200%. The excellent rapid response of the sensors has been confirmed through a large number of resistance measurements during sensor extensions and contractions at different frequencies (Suzuki et al. 2016). This has also confirmed the high linearity of the resistance variation with respect to the strain that further increases the motion and posture tracking precision.

Different versions of the specialized stretchable CNT-based sensors have been commercialized and are currently employed in Yamaha data gloves (Suzuki et al. 2016).

Applications and Implementation Examples

Data gloves employing CNT sensors discussed in the previous section are capable of high fidelity motion tracking (Gelsomini et al. 2021). The

Data Gloves for Hand and Finger Motion Interactions, Fig. 1 A data glove with embedded highly stretchable CNT sensors connected to a dedicated wireless communication device

Yamaha data gloves, for example, are employed for tracking of the subtle hand and finger motions during the play of different musical instruments. Note that such motion tracking has to be implemented with a minimal burden to the artist so that the free natural movements of the hands and the fingers of the player are unimpeded. To facilitate this, a wireless data glove version has been developed as shown in Fig. 1.

Data gloves have been employed in a number of research projects, beginning with an experimental control of a robot hand in exergaming and implementation of hand-based interactions with mobile robots (Demoe et al. 2020). This has been extended with a more general model for data glove-based human-robot communications including experimental support for deafblind through an extended version of the Malossi alphabet (Gelsomini et al. 2022). There is work in progress on the integration of optical and data gloves input for improved sign language analysis and interpretation through machine learning (Raavi et al. 2022).

With respect to medical applications and training, data gloves have been instrumental in researching the user experience aspects in wearable multi-device applications designed for health systems (Salgado et al. 2021) and in conducting experiments related to psychomotor-based virtual medical training (Wilcocks et al. 2021).

Conclusions

The early data gloves incorporated optical sensors consisting of light emitters and photocells connected with flexible rubber tubes. This allowed for tracking of the finger motions with a limited precision through measurements of the attenuated light reaching the photocells. In more advanced applications where higher fidelity finger motion tracking is required, stretchable sensors are deemed more appropriate, and active research is continuing in this field.

Cross-References

- ▶ Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld
- ▶ Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design
- ▶ Tracking Techniques in Augmented Reality for Handheld Interfaces
- ▶ Virtual Hand Metaphor in Virtual Reality

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Data Processor

▶ Plug-in-Based Asset Compiler Architecture

Data Visualization

▶ Artistic Data Visualization in the Making
▶ Immersive Visualizations Using Augmented Reality and Virtual Reality

Data Visualization of Mental Health Issues

▶ Indigenous Knowledge for Mental Health, Data Visualization

DCI

▶ Engaging Dogs with Computer Screens: Animal-Computer Interaction

Dead Space Through the Lens of Resonance

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Synonyms

Survival horror

Definitions

Survival Horror – a subgenre of action-adventure and horror genres where players are frail and are given few weapons, forcing them to approach obstacles through problem-solving rather than combat.

Introduction

The Lens of Resonance is to be mainly associated with how powerful a game makes a player feel and if it gives a good consistency of this power throughout the game. If the player were to feel like they are barely making a difference within the game it may cause the player to feel as if the journey is pointless and may discontinue the game due to this. This can be achieved through many ways, such as completing a certain campaign mission, giving a character powerful attributes, or even giving the character a powerful music ensemble that gives the player a sense of what events are important. Giving players a sense of power can go all the way back to Pong, one of the very first, if not the very first game. It gave the player a feeling of power after winning a game, bragging rights.

In Jesse Schell's book *The Art of Game Design: A Book of Lenses*, the Lens of Resonance states that "to use the Lens of Resonance, you must look for hidden power" (Schell 2019). The Lens of Resonance asks the following questions:

1. What is it about my game that feels powerful and special?
2. When I describe my game to people, what ideas get them really excited?
3. If I had no constraints of any kind, what would this game be like?
4. I have certain instincts about how this game should be. What is driving those instincts?

Dead Space is a survival horror franchise that was published and released by Electronic Arts (EA). There are three games in the franchise. *Dead Space* was released in 2008 for the Xbox 360, Playstation 3, and Windows PC. *Dead Space 2* was released in 2011 for the Xbox 360, Playstation 3, and Windows PC. *Dead Space 3* was released, once again, for the Xbox 360, Playstation 3, and Windows PC in 2013. Rather than making a player feel powerful, the games instead tried to make them feel as weak as possible with methods such as starting the game with a very small health. Story wise, the player character is one of the only humans left on a spaceship full of aliens trying to kill them in several gruesome ways. Progressing through the story gives players new weapons and abilities while also maintaining the very fragile health bar, which gives them a very good sense of power while also severely limiting abilities with their health.

Dead Space made itself different from other games in the horror genre at the time by having the game's setting be in space. The vast emptiness of space can be very unnerving even when the game is at a lull. It can also make the player wonder what other aliens are out there and where they came from. Other than the horror aspect, players loved the look, lore, and the difficulty in killing the aliens.

As in several other horror games, *Dead Space* has several constraints to make the game more interesting, such as having limited ammo and a very weak melee attack that makes players second guess their actions in a game where reactions are everything. Players that plan poorly or act rashly can find themselves in a situation where they run out of ammo and have to resort to their weak melee attack or find a way to bypass an alien

obstacle entirely. If the creators did happen to have no constraints, then there could be aspects such as having unlimited ammo, an increased health bar, and possibly even gorier animations. If these were implemented into the game, it would make the game too easy to beat and defeat the horror purpose. Other horror genre aspects include overly graphic and displeasing animations from the aliens which would not be suitable for the weak-willed.

EA knew that they wanted to bring a new breath of fresh air to the horror genre while keeping a constant pace of action within the game as well. But as the franchise developed, EA's drive changed from survival horror to add more action genre aspects to *Dead Space*. Due to this influence from the action genre, the horror aspects were overshadowed at some points during *Dead Space 3*. This was a common complaint from several critics and the playerbase. Statistics show that people much prefer the first and second games over the third, and this is again because of decreased focus on horror while maximizing the importance of the action sequences.

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Deafblind Communication Interfaces

▶ Data Gloves for Hand and Finger Motion Interactions

Decision-Making

▶ 2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making
▶ Character Artificial Intelligence

Decoupling Game Tool GUIs from Core Editing Operations

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Synonyms

Decoupling systems; Plugin system; Command system; Editor architecture; Game level editor

Definition

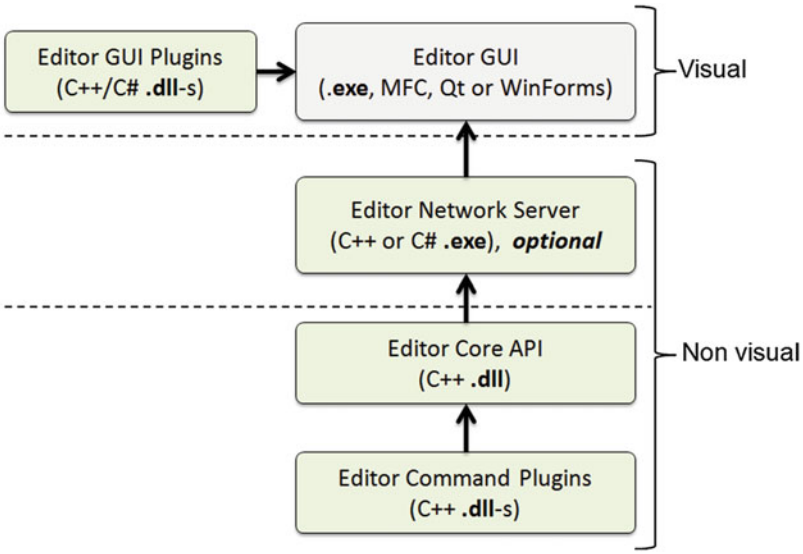
A software architectural method of decoupling the game editing operations from the actual GUI of a game level editor.

Since the early days of video game development when the programmer had to write the code and design and create the levels without the aid of a game editor, the tools to create games have evolved into the must-have game development software we use today. Now the level editors are built into the development kits, and the developer's job is much easier but still filled with potential pitfalls.

In the past few years, it has become common to decouple game level editor operations and functionality from game-specific features, so that the editor can be reused for more games and game types. The same thing has happened on the game engine side: engines have become more and more flexible and reusable.

But problems remain. One big issue with game level editors is complexity and manageability. Once you have added many features to the editor, it will grow in source code size and complexity and become harder and harder to maintain and extend. Another problem is that you have to choose a GUI toolkit to create your interface. That can become a headache if you ever decide to switch to another GUI toolkit, since many editing operations are tied in with the UI code itself.

To address the issue of changing GUI toolkits in these fast and ever-shifting times, we present a



Decoupling Game Tool GUIs from Core Editing Operations, Fig. 1 The editor ecosystem

method of decoupling the visual user interface code from the non-GUI editing operations code in the game level editor or other tools. By separating the UI from core editing functions, you can change to another GUI toolkit in no time, leaving the editing operation code almost untouched. The decoupling operation can be accomplished via C++ editor core functionality code and various editor user interfaces using GUI toolkits like Qt, MS WinForms, WPF, MFC, HTML5/JavaScript, or even a command line editor UI, all using the same editor functionality code as a common hub. Communication between the editor functions and the visual interface is achieved through a command system (basically the command pattern). We will also explore the architecture of a plug-in system using this command communication approach.

Editor Ecosystem

The editor is split into two major logical parts:

- Nonvisual, consisting of the editor core, plug-ins, and their commands (no GUI)
- Visual, created using the UI toolkit of your choice, which will call the commands provided by the plug-ins and editor core

In Fig. 1, we can see the entire editor ecosystem:

The editor GUI can be developed using any UI SDK/API, and it can have its own plug-ins. For example, subeditors like the model editor, cinematic editor, scene editor, material editor, etc. can be hosted by the main editor, and we can even run them as separate tools. Each tool will implement its own UI functionality and will call commands by their name and parameter values (arguments). The editor core will search its registered command list and dispatch the call to the appropriate plug-in command.

We can also have an editor network layer, which waits for tools to connect to it and simply dispatches command calls and sends back their results. There are various other methods of communication between the GUI and the editor core; these methods use IPC (inter-process communication) such as pipes, DDE, and shared memory or files, but sockets are supported on all platforms, so they are the obvious first choice.

Editor Core C++ API

Now let's get to the nuts and bolts of the actual code. First we will declare our editor C++ interface to be used by the plug-ins. We are going to expose plug-in and command methods and

interfaces, a simple history (undo/redo) system, and an event system (used for triggering events in the editor, plug-ins can register themselves as event sinks to receive or trigger events).

Let's start with the building block interfaces related to commands, undo, events, and other primitive constructs. We use a self-contained, independent header file, with only pure interfaces, not relying on external headers so it can be easily wrapped or converted to other languages. (It's especially important to keep the interfaces simple. If you were using something like SWIG (Simplified Wrapper and Interface Generator), e.g., having too many dependencies in the C++ code would complicate things for the SWIG converter, sometimes failing to properly create a wrapper for other languages.)

After we define our simple types like uint32, we define a Handle union to be used as a pointer transporter between the calling application and the editor core internals. This will keep things simpler, since the user can't use the pointer itself anyway (see Listing 1).

Listing 1. A Generic Handle Container.

```
// A generic handle, used to pass pointers in command parameters without
having to know the pointer type


union Handle
{
  Handle()
    : hVoidPtr(NULL)
  {}
  explicit Handle(int32 aVal)
    : hInt(aVal)
  {}
  explicit Handle(int64 aVal)
    : hInt64(aVal)
  {}
  explicit Handle(void* pVal)
    : hVoidPtr(pVal)
  {}
  int32 hInt;
  int64 hInt64;
  void* hVoidPtr;
};
```

We will also need a Version structure to be used in the various version comparisons/validations we will have for the editor API and plug-in versions (see Listing 2).

Listing 2. A Generic Version Holder Structure.

```
// A version structure, holding version information for plug-in
// or editor
```

```
struct Version
{
 Version();
 Version(uint32 aMajor, uint32 aMinor, uint32 aBuild);
 bool operator <= (const Version& rOther) const;
 bool operator >= (const Version& rOther) const;
 Version& operator = (const char* pVerStr);
 uint32 major, minor, build;
};
```


After this, a central point of the editor core API is the main editor interface (see Listing 3), which will provide command, plug-in, and event methods to be used by plug-ins and their commands and also by the main editor skeleton application, which will manage those plug-ins.

Listing 3. The Main Editor Core Interface.

```
// The editor main interface
struct IEditor
{
 enum ELogMsgType
 {
  eLogMsg_Info,
  eLogMsg_Debug,
  eLogMsg_Warning,
  eLogMsg_Error,
  eLogMsg_Fatal
 };
 virtual ~IEditor(){}
 virtual Version GetVersion() const = 0;
 virtual void PushUndoAction(IUndoAction* pAction) = 0;
 virtual bool CanUndo(uint32 aSteps = 1) = 0;
 virtual void Undo(uint32 aSteps = 1) = 0;
 virtual void Redo(uint32 aSteps = 1) = 0;
 virtual void ClearHistory(int32 aSteps = -1) = 0;
 virtual bool RegisterCommand(IPlugin* pPlugin,
         TPfnCommand pCmdFunc,
         const char* pCmdName) = 0;
 virtual bool UnregisterCommand(TPfnCommand pCmdFunc) = 0;
 virtual bool IsCommandRegistered(
         const char* pCmdName) = 0;
 virtual bool RegisterEvent(IEvent* pEvent) = 0;
 virtual bool UnregisterEvent(IEvent* pEvent) = 0;
 virtual bool IsEventRegistered(
         const char* pEventName) = 0;
 virtual bool TriggerEvent(IEvent* pEvent,
```

```
        IEventSink::ETriggerContext aContext,
        void* pUserData) = 0;
 virtual void CallEventSinks(IEvent* pEvent,
        void* pUserData) = 0;
 virtual bool RegisterEventSink(
        IEventSink* pEventSink) = 0;
 virtual bool UnregisterEventSink(IEventSink* pEventSink) = 0;
 virtual IParameterValues* CreateParameterValues() = 0;
 virtual IParameterDefinitions*
       CreateParameterDefinitions() = 0;
 virtual bool Call(
        const char* pCommandName,
        IParameterValues* pParams) = 0;
 virtual void WriteLog(
        ELogMsgType aType,
        const char* pModule,
        const char* pFormat, ...) = 0;
};
```

This is the main editor interface at a glance. Its methods are quite self-explanatory, the most used methods being the Call(...) method, which is used to execute commands by their name and requires a parameter "bag" (optional), and the IParameterValues interface, created before the call by the user using the CreateParameterValues () method and then filling up the parameter values for the command to use.

Plug-ins

The plug-ins are DLLs loaded by the core editor DLL. Each plug-in will expose and register its commands in the editor's ecosystem and provide information about these commands through a manifest file associated with the plug-in's DLL.

A core editor plug-in consists of two files:

- A C++ DLL file, the plug-in code (Example.dll)
- A manifest file (Example.plugin.xml), having the same base file name as the plug-in's DLL (Example), containing information about it

Listing 4 shows an example of a plug-in manifest file.

Listing 4. Plug-in Manifest File.

```
<plugin
  name="Example"
  description="The example editor plugin"
  author="Nicusor Nastase Nedelcu"
  url="http://some.com"
  guid="31D91906-1125-4784-81FF-119C15267FC3"
  version="1.0.0"
  minEditorVersion="1.0.0"
  maxEditorVersion="2.0.0"
```

```
  icon="example.png"
  unloadable="true">
  <dependencies>
    <depends nameHint="OtherPlugin"
      guid="DAA91906-1125-4784-81FF-319C15267FC3" />
    <depends nameHint="SomeOtherPlugin"
      guid="F51A2113-1361-1431-A3EA-B4EA2134A111" />
  </dependencies>
  <commands>
    <command name="get_some_thing"
          info="This command get something">
      <param name="someParam1" type="int32"
           info="this is parameter 1" />
      <param name="someParam2" type="float"
          info="this is parameter 2" />
    </command>
  </commands>
</plug-in>
```

Of course, you can choose any format for the manifest file, like JSON or a custom text format. The important thing is that the plug-in's DLL does not contain any information about the plug-in or its commands. Only the manifest file holds that information.

Plug-ins can be located in a directory structure as shown in Listing 5.

Listing 5. Example of Plug-in and Editor Directory Structure.

```
\Plugins
  \Example1
    Example1.dll
    Example1.plugin.xml
  \Example2
    Example2.dll
    Example2.plugin.xml
EditorCore.dll (the editor code library)
EditorUI.exe (the main editor application)
```

One reason we have chosen to store the plug-in information inside external files is that plug-ins can be listed (with all their details) in the editor's plug-in manager without being loaded into memory. In this way, we can avoid loading some plug-ins we do not need to load but still have information about them. For example, there can be special editor configurations for lighting artists, programmers, or level designers, and these configuration files can be shared among users.

As you can see from the plug-in manifest, we have added information about the name, description, author, and other useful properties but also about the plug-in's dependencies (other plug-in

GUIDs). Optionally, there should be information about the commands, like name, description, parameters, and return values, since we do not store this information in the C++ source files. This information can be used by a debug layer to check the command syntax at runtime and help the discovery of incorrect command calls during development.

For plug-in identification, we will use a GUID in the form shown in Listing 6.

Listing 6. The GUID Structure Used to Identify Plug-ins.

```
// A plug-in unique ID, in a GUID form (see more about Microsoft
// GUID) and online/offline GUID generators
struct PluginGuid
{
  PluginGuid();
  // construct the guid from several elements/parts
  // example:
  // as text: 31D9B906-6125-4784-81FF-119C15267FCA
  // as C++: 0x31d9b906, 0x6125, 0x4784, 0x81,
  // 0xff, 0x11, 0x9c, 0x15, 0x26, 0x7f, 0xca
  PluginGuid(uint32 a, uint16 b, uint16 c, uint8 d,
uint8 e, uint8 f. uint8 g, uint8 h, uint8 i,
    uint8 j, uint8 k);
  bool operator == (const PluginGuid& rOther) const;
  // convert a GUID string to binary
  // string format: "11191906-6125-4784-81FF-119C15267FC3"
  bool fromString(const char* pGUID);
  uint32 data1;
  uint16 data2;
  uint16 data3;
  uint8 data4[8];
};
```

We will use the interface shown in Listing 7 to get information about the discovered plug-ins (gathered from the plug-in manifest files).

Listing 7. The Interface That Describes a Plug-in (from the Plug-in Manifest).

```
struct IPluginInfo
{
  virtual ~IPluginInfo(){}
  virtual const char* GetName() const = 0;
  virtual const char* GetDescription() const = 0;
  virtual const char* GetAuthor() const = 0;
  virtual const char* GetWebsiteUrl() const = 0;
```

```
  virtual PluginGuid GetGuid() const = 0;
  virtual Version GetVersion() const = 0;
  virtual Version GetMinEditorVersion() const = 0;
  virtual Version GetMaxEditorVersion() const = 0;
  virtual const char* GetIconFilename() const = 0;
  virtual bool IsUnloadable() const = 0;
  virtual PluginGuidArray GetPluginDependencies()
              const = 0;
};
```


The plug-in interface methods are easy to understand, but we can say more about the GetMinEditorVersion() and GetMaxEditorVersion(). These methods are used to check whether the plug-in can be loaded into the current editor and help avoid loading plug-ins that are not supposed to run under newer or older editor versions.

The simple creation process of new plug-ins and commands should be the crux of this system; thus, coding new command sets hosted in the plug-ins should be straightforward. In the editor core API, there is an interface each plug-in must implement on its side, called IPlugin, as shown in Listing 8.

Listing 8. The Interface to Be Implemented by a Plug-in.

```
struct IPlugin
{
  virtual ~IPlugin(){}
  virtual void Initialize(IEditor* pEditor) = 0;
  virtual void Shutdown() = 0;
  virtual bool IsCommandEnabled(TPfnCommand pCmdFunc)= 0;
};
```

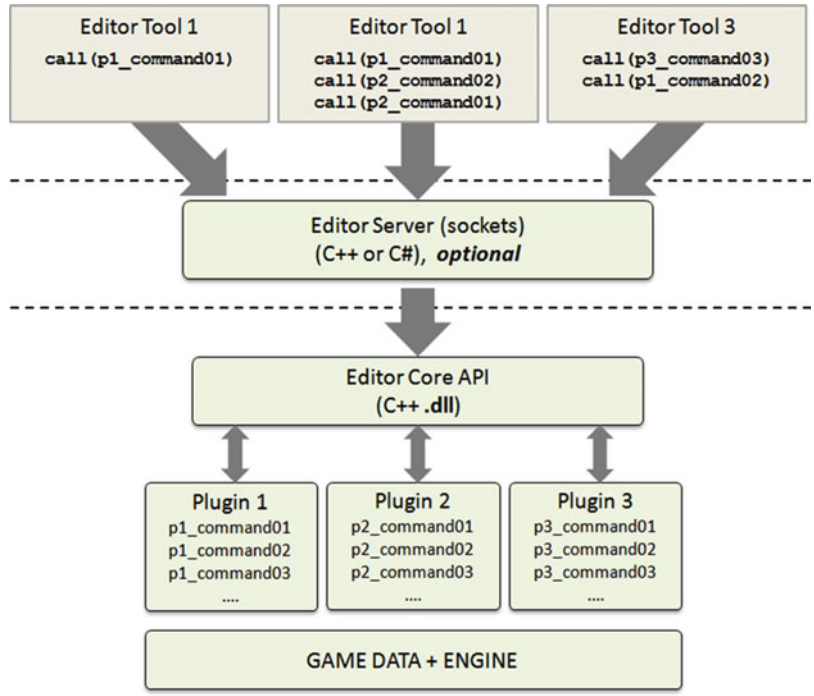
Commands

We will create the editor core as a C++ DLL. This handles the loading of plug-ins that are exposing editing commands. The GUI will call the commands using only the core editor interfaces (see Fig. 2).

The command system is designed as an RPC-like (remote procedure call) architecture, where commands are actually functions that are called with arguments and return one or more values. The call itself can be made directly using the editor core C++ API or the UI editor application connecting sockets to an editor core server, transmitting the command call data and then receiving the returned values.

A command executes only non-GUI-related code so it will not deal with the GUI functions itself, only engine calls and game data. The GUI code will take care of visual representation for the user, and it will call the available commands.

The plug-ins will expose their set of commands, but they will have nothing to do with the GUI itself. You can create a separate plug-in system for the editor's GUI. This is where the true decoupling kicks in, the editor core plug-ins being just "buckets" of non-GUI-related commands with the editor GUI using those commands. There is no need for a 1:1 match between the UI functions and the commands. You only need to expose the basic/simple commands, which should



Decoupling Game Tool GUIs from Core Editing Operations, Fig. 2 The command system diagram

be generic enough to be used by multiple UI tools in various situations.

Command Parameters

When calling the commands, we have the option to send parameters to them, and for this we need to define the parameter type, direction, and description. This information is read from the plug-in's manifest file, but it's optional since the calling of commands is accomplished through a parameter set that is aware of the data types at the moment of setting the values. In Listing 9 we declare the IParameter interface.

Listing 9. The Command Parameter Interface.

```
struct IParameter
{
  enum EDataType
  {
    eDataType_Unknown,
    eDataType_Int8,
    eDataType_Int16,
    eDataType_Int32,
    eDataType_Int64,
    eDataType_Float,
    eDataType_Double,
    eDataType_Text,
```

```
    eDataType_Handle
  };
  enum EDirection
  {
    eDirection_Input,
    eDirection_Output,
    eDirection_InputOutput
  };
  virtual ~IParameter(){}
  virtual const char* GetName() const = 0;
  virtual const char* GetDescription() const = 0;
  virtual EDataType GetDataType() const = 0;
  virtual EDirection GetDirection() const = 0;
  virtual bool IsArray() const = 0;
};
```

The IParameter interface is implemented by the editor core DLL, so plug-in developers do not need to care about the implementation, only what methods it provides, such as the name of the parameter, description, type, direction (if it's an in/out parameter), and whether the parameter is an array of the type specified.

To keep the parameter information in one place, we declare an IParameterDefinitions interface, which holds the parameter information list for a command as seen in Listing 10.

Listing 10. The Parameter Definition Container Interface.

```
struct IParameterDefinitions
{
  virtual size_t GetCount() const = 0;
  virtual IParameter* Get(size_t aIndex) const = 0;
  virtual bool Add(
      const char* pName,
      IParameter::EDataType aDataType,
      const char* pDescription,
      IParameter::EDirection aDirection,
      bool bArray) = 0;
};
```

When calling the commands, we need to pass the parameters. For this, we will use an IParameterValues value "bag," which can set/get parameters and store the values. You can use other approaches for passing parameters, like #define extravaganza or templates to declare several command call forms with from one to ten parameters in their declaration. Listing 11 shows the parameter value interface.

Listing 11. The Parameter Value Container Interface.

```
// Parameter values container, used to pass and receive
// in/out parameter values from a command call
struct IParameterValues
{
  virtual ~IParameterValues(){}
  virtual void SetInt8(const char* pParamName,
                       int8 aValue) = 0;
  virtual void SetInt16(const char* pParamName,
                        int16 aValue) = 0;
  virtual void SetInt32(const char* pParamName,
                        int32 aValue) = 0;
  virtual void SetInt64(const char* pParamName,
                        int64 aValue) = 0;
  virtual void SetFloat(const char* pParamName,
                        float aValue) = 0;
  virtual void SetDouble(const char* pParamName,
                         double aValue) = 0;
  virtual void SetText(const char* pParamName,
                       const char* pValue) = 0;
  virtual void SetHandle(const char* pParamName,
                         Handle aValue) = 0;
  virtual void SetInt8Array(const char* pParamName,
                            Int8Array aArray) = 0;
  virtual void SetInt16Array(const char* pParamName,
                             Int16Array aArray) = 0;
  virtual void SetInt32Array(const char* pParamName,
                             Int32Array aArray) = 0;
  virtual void SetInt64Array(const char* pParamName,
                             Int64Array aArray) = 0;
  virtual void SetFloatArray(const char* pParamName,
                             FloatArray aArray) = 0;
  virtual void SetDoubleArray(const char* pParamName,
                              DoubleArray aArray) = 0;
  virtual void SetTextArray(const char* pParamName,
                            TextArray aArray) = 0;
  virtual void SetHandleArray(const char* pParamName,
                              HandleArray aArray) = 0;
  virtual int8 GetInt8(
                       const char* pParamName) const = 0;
  virtual int16 GetInt16(
                       const char* pParamName) const = 0;
  virtual int32 GetInt32(
                       const char* pParamName) const = 0;
```

```
  virtual int64 GetInt64(
                        const char* pParamName) const = 0;
  virtual float GetFloat(
                        const char* pParamName) const = 0;
  virtual double GetDouble(
                        const char* pParamName) const = 0;
  virtual const char* GetText(
                        const char* pParamName) const = 0;
  virtual Handle GetHandle(
                        const char* pParamName) const = 0;
  virtual Int8Array GetInt8Array(
                        const char* pParamName) const = 0;
  virtual Int16Array GetInt16Array(
                        const char* pParamName) const = 0;
  virtual Int32Array GetInt32Array(
                        const char* pParamName) const = 0;
  virtual Int64Array GetInt64Array(
                        const char* pParamName) const = 0;
  virtual FloatArray GetFloatArray(
                        const char* pParamName) const = 0;
  virtual DoubleArray GetDoubleArray(
                        const char* pParamName) const = 0;
  virtual TextArray GetTextArray(
                        const char* pParamName) const = 0;
  virtual HandleArray GetHandleArray(
                        const char* pParamName) const = 0;
  // delete all parameter values
  virtual void Clear() = 0;
  // get the number of parameters this list holds
  virtual size_t GetCount() const = 0;
  // get the data type of parameter at given index
  virtual IParameter::EDataType GetDataType(
          size_t aIndex) const = 0;
  // get the direction of parameter at given index
  virtual IParameter::EDirection GetDirection(
          size_t aIndex) const = 0;
  // get the data type of parameter at given index
  virtual const char* GetName(size_t aIndex) const = 0;
  // is this parameter an array at given index?
  virtual bool IsArray(size_t aIndex) const = 0;
};
```

To avoid memory fragmentation due to frequent command calls, you would ideally manage the parameter values through a memory pool.

The actual command is a callback function receiving a parameter values set and is declared as shown in Listing 12.

Listing 12. The Command Callback Function Type.

```
typedef void (*TPfnCommand)(IParameterValues* pParams);
```

For debugging and auto-documentation purposes, the editor core API can provide detailed command information through the ICommand interface, which can hold the command description from the plug-in manifest file, plus the command callback function pointer, as shown in Listing 13.

Listing 13. The Command Information Provider Interface.

```
struct ICommand
{
  virtual ~ICommand(){}
  virtual const char* GetName() const = 0;
  virtual const char* GetDescription() const = 0;
  virtual const char* GetIconFilename() const = 0;
  virtual TPfnCommand GetCommandFunc() = 0;
  virtual const IParameterDefinitions*
          GetParameterDefinitions() const = 0;
};
```

Direct Editor API Command Calls

You can call the editor core interface for executing commands directly from C++ or use a wrapper tool for another language like C# (SWIG). To call the commands in C++, we can use the code shown in Listing 14.

Listing 14. How to Call a Command.

```
// create a parameter values bag
IParameterValues* pParams =
          pEditor->CreateParameterValues();
// set some parameter values
pParams->SetInt32("someParam1", 123);
pParams->SetText("someName", "Elena Lenutza Nedelcu");
pParams->SetText("someOtherName", "Dorinel Nedelcu");
// the actual command call
pEditor->Call("someCommandName", pParams);
// retrieve the return values
float fRetVal = pParams->GetFloat("returnSomeValue");
int someNum = pParams->GetInt32("otherValue");
```

Remote Editor API Command Calls

We can use sockets for calling the commands remotely, since they're cross-platform and relatively easy to use from any language or environment. On the editor core DLL side, we will have a network server executable, and on the editor UI side, we will have a network client sending and receiving command data.

Communication can be accomplished through reliable UDP or TCP. For a local editor on the same machine, TCP would be okay even for LAN scenarios. If you are not so keen on using TCP because you consider it slow, UDP should suffice to send commands. All logic remains the same in this networked scenario, but this setup opens the doors to online collaboration of multiple clients operating on the same data on the server. We're not going to discuss this here, since it's a subject for a whole article (a challenging and interesting one!).

Networked editing is also feasible for debugging and remote in-editor live tutorials.

Putting It All Together

Implementing the Main Editor Application

The editor can be implemented in Qt (just an example, chosen for its cross-platform support, though C# can also be supported using Mono on platforms other than Windows). This editor will be an empty skeleton that contains a plug-in manager dialog and nothing else, since all the functionality will be brought in by the plug-ins. Once again we need to emphasize the separation of the plug-in systems. They are two systems, one for the UI and one for the editor core commands. UI plug-ins will use the commands found in the editor core plug-ins (see Fig. 1 at the beginning of this article). The main UI editor can even do without a plug-in system if it's so intended, but the editor core command plug-ins will still exist.

Implementing a Plug-in with Commands

To ensure that you have a simple way of implementing new commands, the method of declaring commands and plug-ins must be straightforward.

In the editor core API, the IPlugin is the interface a plug-in must implement. To help rapid plug-in development, you can write a series of macros. In our sample plug-in, implementing a few commands would look like the code shown in Listing 15.

Listing 15. A Sample Plug-in Implementation.

```
#include "EditorApi.h"
void example_my_command1(IParameterValues* pParams)
{
  // get our calling parameter values
   int numberOfHorses =
       pParams->GetInt32("numberOfHorses");
  std::string dailyMessage =
       pParams->GetText("dailyMessage");
  // do something important here for the command...
  // return some parameter values
  pParams->SetDouble("weightOfAllHorses", 1234.0f);
  pParams->SetText("userFullName", "Iana Lomos");
}
void example_my_command2(IParameterValues* pParams)
```

```
{
  // now here we'll try to grab an array
  FloatArray magicFloats =
        pParams->GetFloatArray("magicFloats");
  for (size_t i = 0; i < magicFloats.count; ++i)
  {
    float oneMagicFloat = magicFloats.elements[i];
    // do something majestic with the float...
  }
  // we do not need to return any value now
}
BEGIN_PLUGIN
void Initialize(IEditor* pEditor)
{
  REGISTER_COMMAND(example_my_command1);
  REGISTER_COMMAND(example_my_command2);
}
// used to check if a command is disabled at that time
// can be helpful for UI to disable buttons in toolbars
// or other related visual feedback
bool IsCommandEnabled(TPfnCommand pCmdFunc)
{
  return true;
}
void Shutdown()
{
}
END_PLUGIN
```

Note that BEGIN_PLUGIN and END_PLUGIN are macros hiding the start/end of the IPlugin interface implementation. The Initialize method is called when the plug-in is loaded into the editor. We are also registering the plug-in's commands by just referring invoking the global functions example_my_command1 and example_my_command1. The Shutdown method is called when the plug-in is unloaded (no need to call the unregister commands; this can be tracked and executed by the editor core itself, since it knows the IPlugin pointer when the commands are registered). The IsCommandEnabled method is used to verify whether a command has the status of "enabled" so it can be called/executed.

Be sure to name the commands in a way that avoids conflicts. Usually some sort of group naming, like the name of the plug-in and the actual command action name, should be enough, like assets_reload, assets_set_tag, assets_delete, or if you prefer camel-case style, Assets_SetTag.

The generated plug-in will be named example.dll and will be accompanied by its manifest file, example.plugin.xml. Of course the plug-in must export a CreatePluginInstance global function so the editor core can load it and instantiate the IPlugin implementation.

Events

To make the plug-ins aware of events occurring in the editor ecosystem, they can register themselves as event sinks, as shown in Listing 16.

Listing 16. An Event Sink, Which Can Be Implemented by the Plug-ins.

```
// Every plug-in can register its event sink so it can
// receive notifications about events happening in the
// editor ecosystem, coming from other plug-ins or the
// editor core itself
struct IEventSink
{
  // When the event sink call is received, before, during or
  // after the event was consumed
  // The eTriggerContext_During can be used to have
  // lengthy events being processed and many triggered to
  // update some progress bars
  enum ETriggerContext
  {
    eTriggerContext_Before,
    eTriggerContext_During,
    eTriggerContext_After
  };
  virtual ~IEventSink(){}
  virtual void OnEvent(IEvent* pEvent,
            ETriggerContext aContext,
            void* pUserData) = 0;
};
```

The IEventSink::OnEvent method is called whenever an event is triggered by other plug-ins or their commands and broadcast to the registered event sinks. The method receives a pointer to the triggered event interface (see Listing 17).

Listing 17. An Event, Implemented by the Trigger Code.

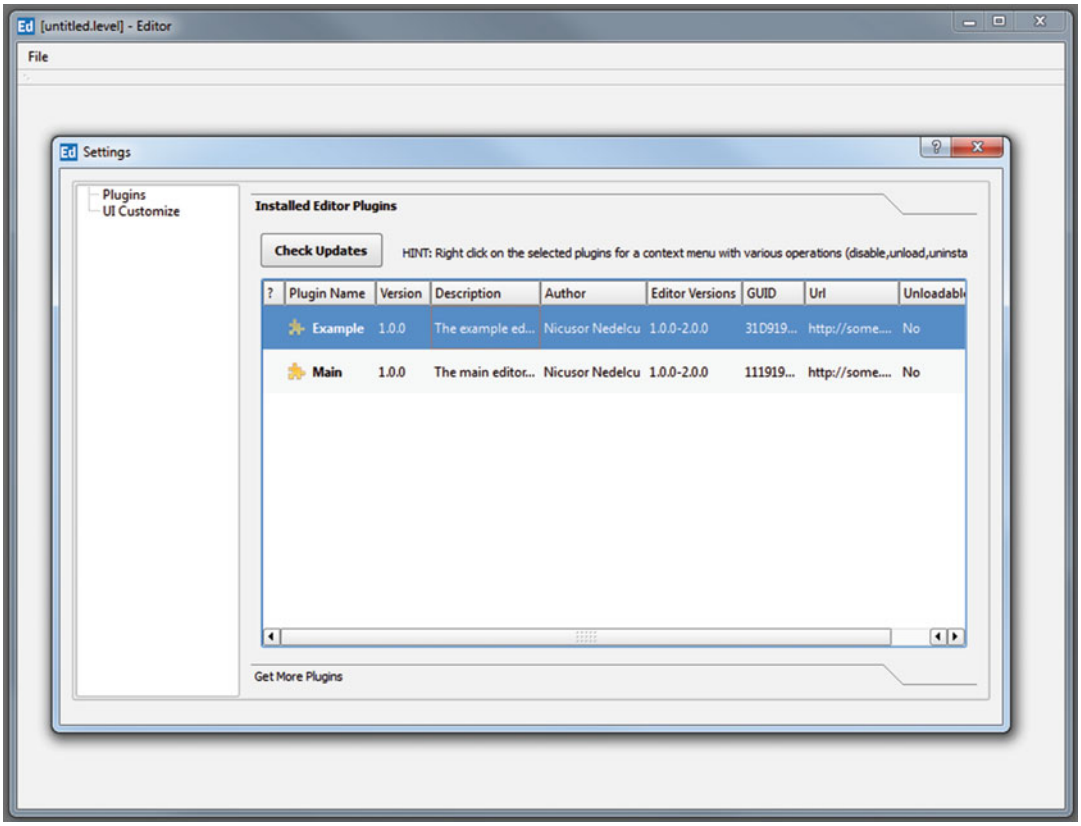
```
// An event is triggered when certain actions are happening
// in the editor or its plug-ins. For example we can have an
// event at Save level or an object moved with the mouse
struct IEvent
{
  virtual ~IEvent(){}
  virtual const char* GetName() = 0;
  virtual void OnTrigger(void* pUserData) = 0;
  virtual void* GetUserData() = 0;
};
```

Listing 18 shows how to trigger an event.

Listing 18. Creating, Registering, and Triggering an Event.

```
// we declare an event
struct MyEvent: IEvent
{
  virtual const char* GetName()
  {
    return "MyCoolEvent";
  }
  // this will be called when the event is triggered,
  // before being broadcast to all the event sinks
  // so the event can even modify the user data
  virtual void OnTrigger(void* pUserData)
  {
    // modify or store the pUserData
    m_pData = pUserData;
  }
  virtual void* GetUserData()
  {
    return m_pData;
  }
  uint8 m_pData;
} s_myEvent;
// we register an event (usually in the Initialize method
// of the plug-in)
...
REGISTER_EVENT(&s_myEvent);
...
// in some command, we trigger the event
void my_command(IParameterValues* pParams)
{
  uint8* pSomeData;
  // ....... do things with pSomeData
  g_pEditor->TriggerEvent(
        &s_myEvent,
        IEventSink::eTriggerContext_After,
        pSomeData);
}
```

In some plug-ins, an event sink registered for a particular event would be notified of the event being triggered, as shown in Listing 19.



Decoupling Game Tool GUIs from Core Editing Operations, Fig. 3 Skeleton editor UI application and settings dialog, with the plug-in manager (made with Qt)

Listing 19. Creating and Registering an Event Sink.

```
// declare our event sink
struct MyEventSink: IEventSink
{
  void OnEvent(IEvent* pEvent,
        ETriggerContext aContext,
        void* pUserData)
  {
    // is this the event we're looking for?
    if (!strcmp(pEvent->GetName(), "MyCoolEvent"))
    {
      uint8* pEventData = pEvent->GetUserData();
      // ...do things when that event was triggered
    }
  }
} s_myEventSink;
// inside the plug-in's Initialize method, register
```

```
// the event sink
...
pEditor->RegisterEventSink(&s_myEventSink);
...
```

In Fig. 3, you can see a demo application of this system, with the editor skeleton having just one menu item, and a setting dialogue where plug-ins are managed.

Conclusion

Decoupling the UI from core editing functionality helps the development and fast feature-set iteration of game creation tools, since fewer hard-coded dependencies and monolithic schemes are used. The tools can be extended and used for a wide range of projects, the editor itself being quite agnostic to the game type and even the engine used. The solution presented here can be implemented in many ways, from the command system interfaces to the UI or plug-in system. In all cases, one thing remains constant: the use of UI-independent editing operations is separated from the tools' GUI using the command layer. I hope this article inspires you to make the right choices when creating extensible, elegant solutions for your game development tools.

Decoupling Systems

▶ Decoupling Game Tool GUIs from Core Editing Operations

Deep Learning

▶ Deep Learning Algorithms for 3D Reconstruction
▶ Deep Reinforcement Learning in Virtual Environments
▶ Human Interaction in Machine Learning (ML) for Healthcare
▶ Machine Learning for Computer Games

Deep Learning Algorithms for 3D Reconstruction

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Synonyms

3D Reconstruction; Deep Learning; Human Detection

Definition

3D human reconstruction is an important research topic in VR/AR content creation, virtual fitting, human-computer interaction, and other fields. Deep learning theory has made important achievements in human motion detection, recognition, tracking, and other aspects, and human motion detection and recognition is an important link in 3D reconstruction. In this entry, the deep learning algorithms in recent years, mainly used for human motion detection and recognition, are reviewed, and the existing methods are divided into three types: CNN-based, RNN-based, and GNN-based. At the same time, the main stream data sets and frameworks adopted in the references are summarized. The content of this entry provides some references for the research of 3d reconstruction of human motion.

Introduction

The earliest study of human movements was proposed by Johansson (1973). The motion of the main joints is described by a few bright spots

against a dark background. The effectiveness of the kinetic-geometric model for visual vector analysis is verified. This study opens the door for human motion analysis. Since almost all human behavior understanding needs to be based on accurate motion reconstruction, human motion reconstruction is a hot topic in the field of computer vision. At present, the 3D reconstruction technology of human motion has been widely applied in human-computer interaction, costume design, virtual fitting, and games.

From the technical point of view, there are many deep learning algorithms for 3D reconstruction of human motion detection, and different algorithms have different processing methods. Based on the standard RNN model typically used for human motion, Martinezet et al. (2017) develop a sequence-sequence model with residual connections. Its performance is better than the early human motion prediction work and achieves good results. Li et al. (2020) propose a dynamic multi-scale graph neural network (DMGNN) which is adaptive during training and a multiscale graph computational unit (MGCU). Despite the continuous improvement of deep learning algorithms, motion pose estimation has been a recognized problem for researchers in the study of computer vision. A good attitude estimation method needs to be robust to occlusion and deformation, stable to changes caused by factors such as illumination and clothing, and the human body is a hinged object with different attitudes, so it is difficult to keep absolute static.

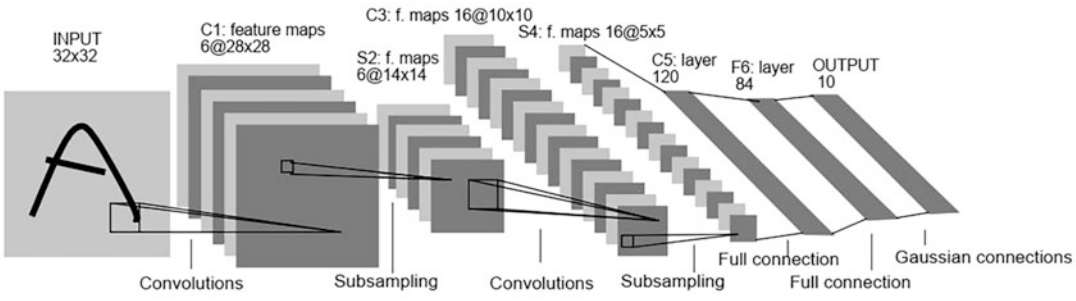
This paper reviews the 3D reconstruction of human motion detection based on deep learning algorithm. Firstly, the foundation of deep learning algorithm is introduced in detail. Then, according to different reconstruction methods, the latest research progress is introduced from two aspects of direct reconstruction and two-stage reconstruction. Finally, the framework of deep learning and the data set used in the research literature are introduced.

D

Deep Learning Fundamentals

For different types of data and problems, people have studied all kinds of neural network structural models. Now, the mainstream methods of deep learning technology in 3d reconstruction of human motion detection are mainly CNN, RNN, and GNN as the basic framework or their combination, and has achieved remarkable results.

Figure 1 shows the overall structure of convolutional neural network, which is mainly composed of convolution layer, activation function, pooling layer, and full connection layer. LeCun et al. first proposed Convolutional Neural Network (CNN) in 1998 (LeCun et al. 1998). The structure of LeNet network is divided into eight layers, which mainly uses the principle of image local correlation to process image data. AlexNet is a Convolutional Neural Network developed by Krizhevsky et al. In the ILSVRC competition of that year, the error rate of Top5 is reduced to 15.315%. Compared with Lenet-5, AlexNet uses a deeper network structure, with 5 convolution layers, 3 full connection layers, 60 million parameters, and 65,000 neurons. AlexNet uses two Gpus for calculation, which greatly improves the computing efficiency. The sigmoid function and Tanh

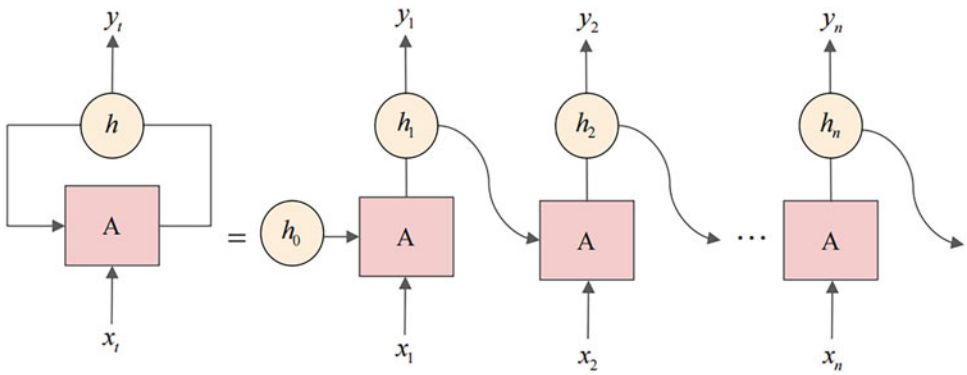


Deep Learning Algorithms for 3D Reconstruction, Fig. 1 Schematic diagram of CNN (LeCun et al. 1998)

function are replaced with the non-saturated nonlinear function ReLU function (Krizhevsky et al. 2012). Since AlexNet, deep learning has enjoyed a Renaissance. In the following years, various Convolutional Neural Network models based on the basic structure of AlexNet spring up, such as VGGNet, GooleNet, and ResNet (He et al. 2016). The proposal of ResNet is an improvement on the degradation of deep network structure, which is a milestone event in the history of CNN image processing. Since then, the research focus of the academia has changed from how to improve the accuracy of the neural network to how to achieve the same accuracy with less parameters and calculation. SqueezeNet is a typical example (Iandola et al. 2016). With the deepening of deep learning research, more CNN models and design ideas have been adopted into the network model design of 3D human motion reconstruction, which greatly promotes the development of 3D human motion reconstruction technology.

RNN (Recurrent Neural Network) is used to process sequence data. The difference between CNN and RNN is that a directional loop is formed between neurons, in which the hidden state at the last moment and the input at this moment are both the input of neurons, so the network can remember the information at the previous moment. The structure of circulation unit is shown in Fig. 2. RNN is unidirectional propagation. Based on this, bidirectional RNN (Schuster and Paliwal 1997) is proposed. In the process of training RNN, due to the repeated multiplication of weights, the problems of gradient disappearance and explosion are easy to occur, and it is difficult to learn for a long time. Therefore, RNN can only deal with the problems of short sequence dependence. LSTM (Hochreiter and Schmidhuber 1997) is an improvement on RNN. Different from the cyclic layer in the basic structure of RNN, LSTM uses a gate control mechanism in the memory unit and combines short-term memory with long-term memory. It can learn the content with long time dependence and alleviate the problem of gradient explosion and disappearance to a certain extent. GRU is improved on the basis of LSTM. It has the same effect as LSTM, but it is improved in structure. GRU (Cho et al. 2014) simplifies the three "gates" of LSTM structure to two "gates". To prevent the gradient from disappearing and exploding, IndRNN (Li et al. 2018) introduces Relu as the activation function, and separates the neurons in the layer, which can also build a deeper and longer network and make the network learn for a long time. Dual-path Recursive Neural Network (DPRNN) (Luo et al. 2020) is an effective and simple way to organize RNN layers in deep structures to make RNN model long sequences. The experimental result shows that replacing one-dimensional CNN with DPRNN in TasNet can improve the experimental results (Fig. 3).

Scarselli et al. (2008) first proposed the concept of graph neural network in their entry. In the entry, they used neural network on graph structure data. GNN also has many limitations and is suitable for shallow structures, most with no more than three layers. Graph Convolutional Neural Network (GCN) (Kipf and Welling 2016) summarizes the convolutional operation from grid data to graph data, which is a combination of CNN and



Deep Learning Algorithms for 3D Reconstruction, Fig. 2 Schematic diagram of RNN (Schuster and Paliwal 1997)

graph topology structure, and implements multi-layer stacking. When constructing GCN, two methods, spectral method and non-spectral method, are usually followed. The Graph Attention Network (GAT) (Busbridge et al. 2019) introduces the attention mechanism based on GCN. Masked self-attentional layers is introduced to improve the disadvantages of graph convolution. Assigning corresponding weights to different adjacent nodes requires neither matrix operation nor prior knowledge of the graph structure. The model has better performance and is more robust to disturbances. Relational Graph Attention Networks (Busbridge et al. 2019) applies the Attention mechanism to graph convolution and adds relational information to the model, thus extending the non-relational graph attention mechanism. Relational Graph Attention Networks is an extension of GAT and has broader applications. Aiming at the problems of GCNs, Self-Supervised Semantic Alignment for Graph Convolution Network (SelfSAGCN) is proposed. Identity Aggregation and Semantic Alignment are its two key approaches. This algorithm reduces over-smoothing and enhances the similarity between unlabeled features and labeled features of the same class. Experimental results show that the algorithm is better than other methods in various classification tasks (Yang et al. 2021).

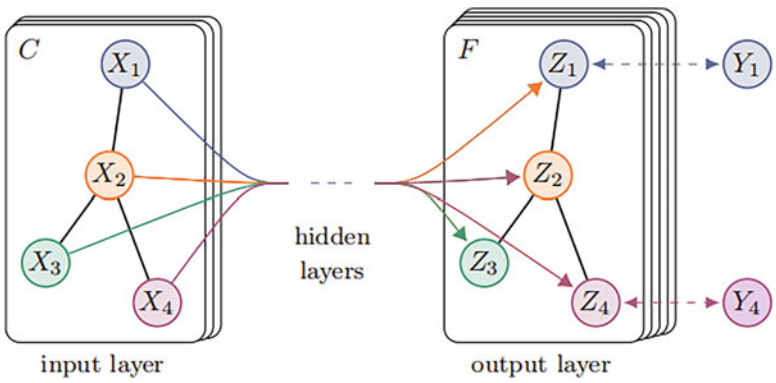
3D Reconstruction with Deep Learning

3D reconstruction of human motion detection is a very complicated process. As discussed earlier, the mainstream approaches to deep learning technologies have their own characteristics. Depending on the specific properties of these methods, how to apply these deep learning methods to 3D reconstruction of human motion is extremely important. Based on the types of deep learning methods, this section elaborates 3D reconstruction of human motion detection from the following three aspects: (i) CNN based, (ii) RNN based, human motion reconstruction.

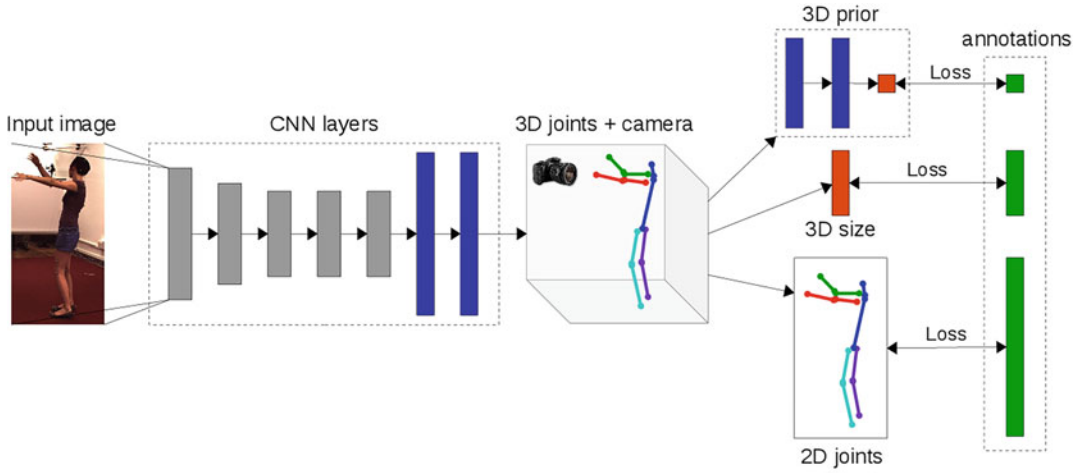
D

CNN Approach

CNN is the most widely used neural network among all the neural networks, and it is also the first one used for 3D reconstruction of human motion detection. It can process images and any kind of data that can be converted into a similar image structure. Tompson et al. (2014) propose to use CNN to make pose estimation and use heat map to regression the key points. The method optimizes the prediction results by using the structural relations between key points and markov random field. LeCun's team proposes a novel architecture in which refined models are cascered with the latest CNN models, including an effective "position refinement" model that can be trained to estimate joint offset positions in small areas of the image (Tompson et al. 2015). Stacked hourglass networks is a cascade of funnel-like neural networks, each of which acts as an encoder and decoder to extract features and generate heat map results (Newell et al. 2016). In recent years, many studies on human pose estimation (single or multiple) have been based on this basic network structure, as well as another network structure, OpenPose. OpenPose is an open source project at Carnegie Mellon University based on models



Deep Learning Algorithms for 3D Reconstruction, Fig. 3 Graph Convolutional Neural Network (Kipf and Welling 2016)



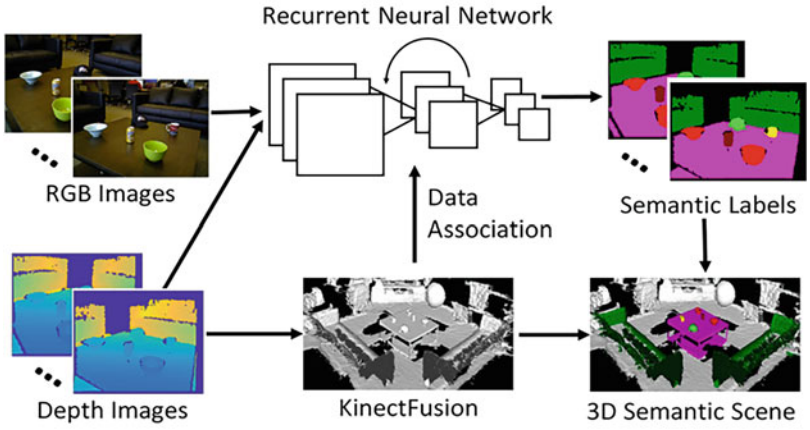
Deep Learning Algorithms for 3D Reconstruction, Fig. 4 Multi-Resolution Sliding-Window with Overlapping Receptive Fields (Brau and Jiang 2016)

from three papers. One of the papers (Cao et al. 2017) describes the 2D pose detection method PAF (Part Affinity Fields) in multi-player images, which first detects various points and then connects them with individuals to realize real-time detection of multiple people. Ke et al. (2018) improve the recent deep convolution and deconvolution hourglass model in four key points, and develop a robust multi-scale structural perceptual neural network for human pose estimation. Figure 4 shows deep learning architecture consists of three main components, a convolutional neural network (CNN), a camera projection and bone length computation layer, and a 3D pose prior network (Brau and Jiang 2016).

RNN Approach

The dynamic characteristics and context-dependent information of action can be captured by using recurrent neural network (RNN). Based on layered bone input, a multi-layer RNN framework is proposed by Du et al. (2019). In the algorithm, the human body is divided into five parts, and then each part is input into five subnets for training. In the end, the extracted features are input into a single layer perceptron to determine the action category. Based on the RNNs with Long Short-Term Memory (LSTM), an attentional mechanism is proposed to learn temporal and spatial features of skeleton data in human motion recognition tasks (Yang et al. 2020). In the attention subnetwork of spatial dimension, the author uses LSTM network to learn the relationship between the nodes of the current frame and the nodes of the previous frame, form a currently input attention map frame node data, and automatically find the current frame data of skeleton points, which has the greatest impact on action recognition. In the attention subnetwork of the time dimension, the author uses the LSTM network to learn the relationship between the current frame and the previous frame, to form the attention map of the current input frame data, and automatically learn which video frames contribute the most to action recognition. Zhang et al. (2017) propose an adaptive recursive neural network (RNN) based on LSTM structure, instead of relocating the skeleton based on human defined prior criteria. This allows the network itself to adapt from one end to the other to the most appropriate point of view. Xiang and Fox (2017) integrate DA-RNN's with KinectFusion (Newcombe et al. 2011) for semantic 3D scene reconstruction. KinectFusion was known as an accurate real-time mapping of indoor scenes in variable lighting conditions (Fig. 5).

Multistage convolutional neural network (CNN) has made advanced achievements in realizing single image human posture estimation, but



Deep Learning Algorithms for 3D Reconstruction, Fig. 5 The pixel labels provided by the RNN are integrated into the 3D semantic map (Newcombe et al. 2011)

its application to video requires a lot of calculation, and there will be performance degradation and jitter. A new recursive LSTM model is proposed for video pose estimation (Luo et al. 2018). Artacho and Savakis (2020) proposed UniPose and Unipos-LSTM architectures for single image and video pose estimation respectively. This structure can better understand the context information in the framework and help to estimate the posture of the subject more accurately.

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Deep Reinforcement Learning

▶ Deep Reinforcement Learning in Virtual Environments

Deep Reinforcement Learning in Virtual Environments

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Synonyms

Deep learning; Deep reinforcement learning; Humanoid avatar; Reinforcement learning; Unmanned aerial vehicle; Virtual reality

Definitions

Deep learning (DL) is a special type of machine learning (ML) (Yu et al. 2012; De et al. 2018) in which an artificial neural network (ANN) is utilized to map a set of input parameters into a set of outputs. DL works with labeled datasets as training samples which usually involve complex, high-dimensional raw input data (Lou et al. 2018). It needs less manual feature engineering than prior ML methods (Liang et al. 2018). DL has enabled significant progress in many application fields such as computer vision, games, and virtual and augmented reality (Khiew et al. 2019).

In artificial intelligence (AI) game designs, behavior of the in-application non-player character (NPC) is a key issue. It will largely affect the overall quality of the game user experience. Instead of designing specific NPC algorithms, the NPC agent can be trained with reinforcement learning (RL) in the entire behavior system by configuring the desired game environment and a set of hyperparameters. RL is conceptualized as a Markov decision process (MDP). Refer to Fig. 1, an Agent at an execution step t is defined by a State S_t. The Agent arbitrarily takes an Action A_t, which results in a change of the Environment. The Environment provides the Agent with a feedback Reward/Penalty score R_{t+1} for its next execution

step $t + 1$, and transits the Agent to next State S_{t+1} according to the environment dynamics. In a trial-and-error manner, the Agent attempts to learn a policyfrom observations to actions, in order to maximize/minimize its expected sum of Reward/Penalty scores.

In practice, an RL policy is dependent on a high-dimensional vector of inputs. Deep reinforcement learning (DRL) is to implement a DL network with an RL policy. In this study, DRL is to solve the problem of an NPC learning to make decisions in the AI game. In particular, DRL allows an NPC agent to make decisions from high-dimensional and unstructured input data without manual engineering of the state space. The implemented DRL algorithms are able to take in a very large set of inputs, for example, all pixels in a video game, and decide what actions to take to optimize an objective, for example, maximizing the game score.

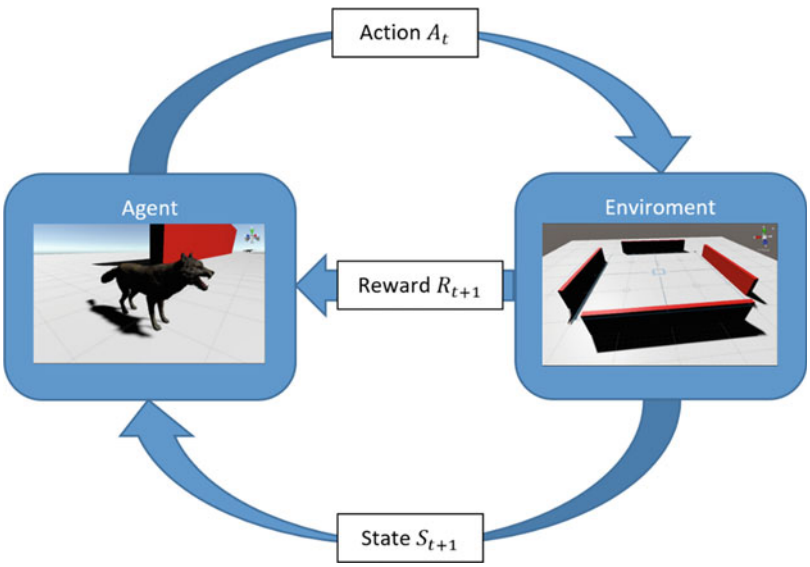
Applications of Deep Reinforcement Learning in Virtual Reality

DRL proves to be a promising tool for real-time feedback to virtual reality (VR) and intelligent virtual environments (IVE) (Wang et al. 2019a, b, 2020; Kumar et al. 2016; Liu et al. 2020). In the applications, DRL ANN is implemented with a specific reinforcement learning policy according to the problems to be solved. A machine learning agent is rewarded for actions that achieve the target outcome and penalized if not. The DRL applications in two case studies are demonstrated.

Case Study 1

The conventional agricultural unmanned aerial vehicle (AUAV) is based on the principles of aerodynamics and atmospheric turbulence, and its flight control system involves a complex process and needs a long learning curve. It requires the operators to be familiar with the aerodynamic characteristics of the AUAV, as well as the agricultural tasks such as spraying; the operators have also to be vulnerable to external meteorological and geographical environments which are constraint by the climate conditions; and worse, failures in the operations often lead to crashes of the drones, which is costly.

To largely reduce the dependence on the physical settings for the AUAV tasks, with references to our other VR autonomous movement controls (Zhao et al. 2021a, b) and path finding algorithms (Zhang et al. 2021a), DRL is applied into a VR AUAV. Modeling based on our four-rotor AUAV,



Deep Reinforcement Learning in Virtual Environments, Fig. 1 Reinforcement learning for an agent to adapt to the environment

and targeting at complex external meteorological and geographical environments as well as irregular plants, the VR AUAV flight is simulated and controlled using its machine learning agent. Briefly,

(a) A momentum balance model (MBM) of four-rotor AUAV and its intelligent runtime control system is designed.
(b) Virtual flight controls of the four-rotor AUAV by graphical user interface (GUI), including take-off, landing, forward flight, left/right turn, are implemented with its flight parameters for optimization in real time.
(c) DRL for the roam function is implemented to acquire the flight attitude and position information of the drone, as well as simulation of the control of agricultural spraying and sowing with particle systems, a VR simulation shown in Fig. 2.

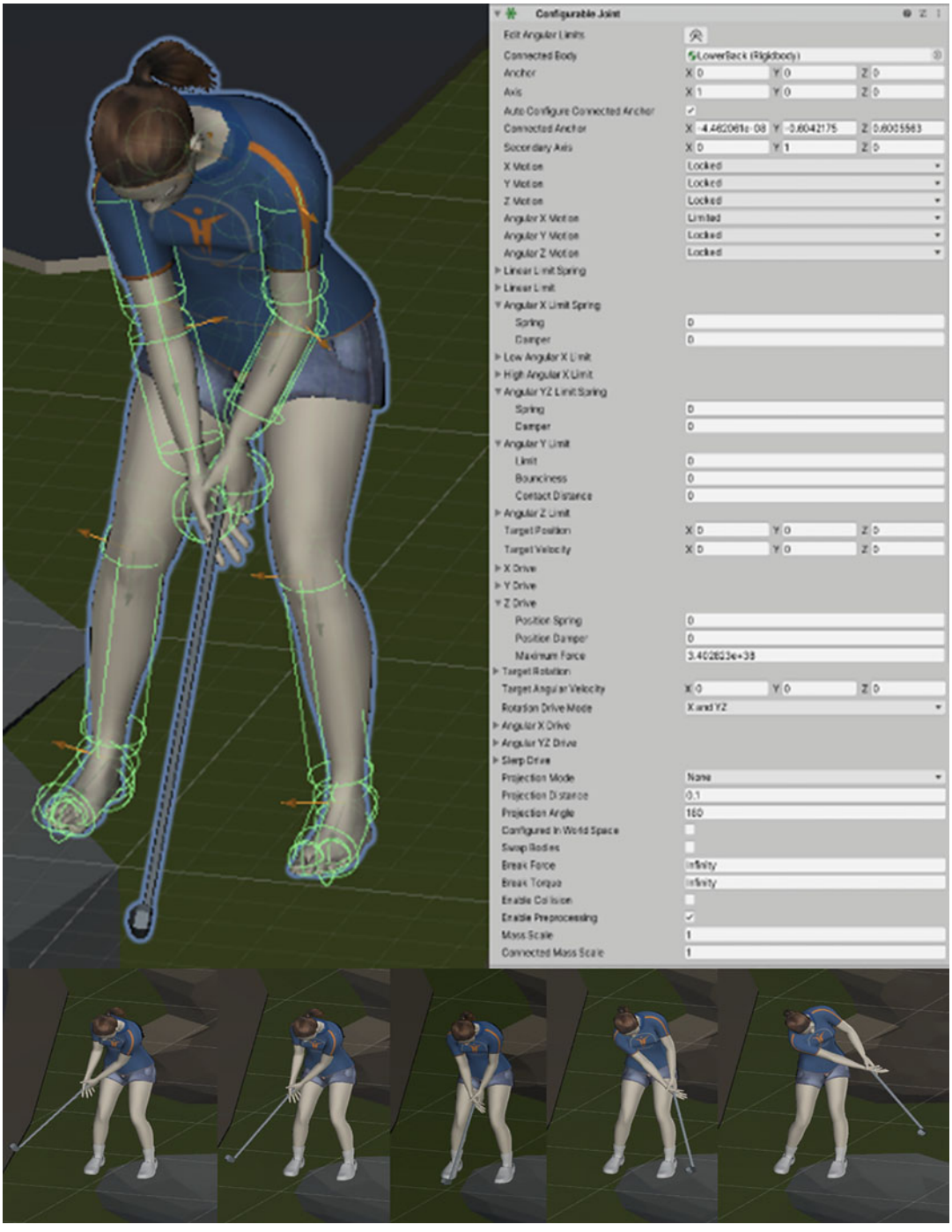
Case Study 2

A VR golf training environment is designed, with two humanoid avatars, one representing the trainer and the other for the machine learning agent. Configurable joints and rigid bodies are added to the body parts of the humanoid avatar, as shown in Fig. 3 (upper). This allows for physics to be added to the character as well as movements of the character to be customized by configuring the X, Y and Z motion and angular motion of each body part (Wu et al. 2004; Cai et al. 2016, 2017). By locking or limiting certain X, Y, and Z motion and angular motion, it prevents the joints from moving erratically in the VR game.

In the DRL processes for the VR game, as shown in Fig. 3 (lower), the humanoid agent acts based on the observations generated and is given a reward correspondingly (Zhang et al. 2021b; Ming et al. 2021). The various attributes of the humanoid agent such as the number of actions to be taken are defined by the behavior component (Leong et al. 2020). Briefly,

(a) Before training is undertaken, the humanoid agent possesses a Learning Behavior where the attributes are undefined. At the end of the training session, an ANN file is generated. By attaching the trained ANN file to the humanoid agent, the initial Learning Behavior transfers into Inference Behavior and the attributes become defined.
(b) These attributes are passed on to the master controller which calculates the offset between the rotation, angular momentum, center of mass of the agent's body parts and trainer's body parts. The observations made by the master controller are used by the agent component to compute the corresponding reward.
(c) The difference in these values between the agent and trainer are tracked as observations. During training, the values can be seen from the master controller script attached to the humanoid agent. Through

Deep Reinforcement Learning in Virtual Environments, Fig. 2 DRL for VR AUAV flight controls in IVE of agricultural spraying



Deep Reinforcement Learning in Virtual Environments, Fig. 3 DRL for VR golf swing

RDL, the agent continuously makes decisions that will minimize the difference between these values.

(d) The reward function incentivizes the agent to move closely to the trainer's action. It is obtained by adding the respective reward earned from the observations made.

Conclusions

In the two case studies on VR applications, DRL has been proven to be effective for training intelligent and autonomous in-game agents. Nevertheless, while a virtual policy in RL is easy to realize compared with its counterpart in real-world, the virtual environments with complex physics are yet to be researched. This is critical in scenarios when precision of the agent is seen as the priority in the learning process (Zhao et al. 2021c). More robust and efficient reinforcement learning algorithms should be investigated for real-time systems of Virtual Reality and Intelligent Virtual Environments.

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Defamiliarization

▶ Design of Alienation in Video Games

Dehumanization

▶ Uncanny Valley in Virtual Reality

Delaunay Tesselations

▶ Delaunay Triangulation

Delaunay Tessellations

▶ Constrained Edges and Delaunay Triangulation

Delaunay Triangulation

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Synonyms

Delaunay Tesselations; Delone Tesselations; Delone triangulation

Definition

Delaunay Triangulation is a geometrical structure widely used in Computational Geometry. It was proposed by Boris Nikolaevich Delone (1890–1980) in 1934. Basically, given a set of n vertices $V(n)$ $(n \geq 3)$ a Delaunay Triangulation is a net of non-overlapping triangles whose set of vertices is $V(n)$.

Introduction

A triangulation is a connection of vertices by edges, which form a set of non-overlapping triangles (Sinclair 2016). The most known triangulations in the literature are: Greedy Triangulation (Dickerson et al. 1994), Triangulation of Garey (Garey et al. 1978), Radial Sweep (Hjelle and Dæhlen 2006), and Delaunay Triangulation (de Berg et al. 2008).

The Delaunay Triangulation for the set of vertices $V(n)$ satisfies four properties: (i) local-empty circle: for each circumcircle C_{ijk} created for a Delaunay triangle t_{ijk}, there is not any vertex v_l of other triangle falling inside the circumcircle C_{ijk} (de Berg et al. 2008), (ii) Maximize the minimum angles, (iii) a Delaunay Triangulation is unique (Verbree 2010), and (iv) the boundary of a Delaunay Triangulation for a set of vertices $V(n)$ is the convex hull of $V(n)$.

A Delaunay Triangulation has a dual graph called a Voronoi diagram, which is formed by using circumcenters of Delaunay triangles (or tetrahedra), thus some authors have taken advantage of this to explore both geometrical structures (Watson 1981; Chew 1990; Agarwal et al. 2015; Allen et al. 2016). The most common methods to construct a Delaunay Triangulation are Lawson method (Lawson 1977), Bowyer method (Bowyer 1981) and Watson method (Watson 1981).

For the set of vertices $V(n)$ shown in Fig. 1a, it is created a Delaunay Triangulation (see Fig. 1b). The convex hull for the set of vertices $V(n)$ is depicted in Fig. 1c. Whereas Fig. 1d depicted the circumcircles, and Fig. 1e shows the centers for each circumcircle. Finally, the Voronoi diagram is represented in Fig. 1f.

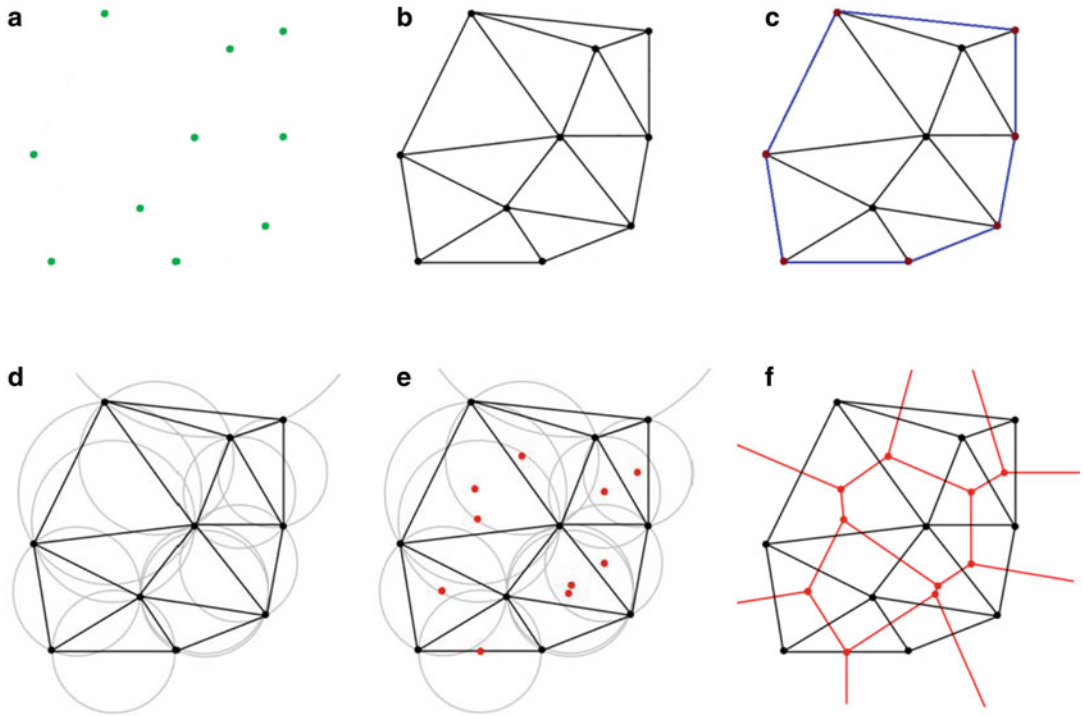
Properties

A Delaunay Triangulation has to satisfy four properties: Local empty circle, maximize the minimum angles, uniqueness, and boundary (convex hull).

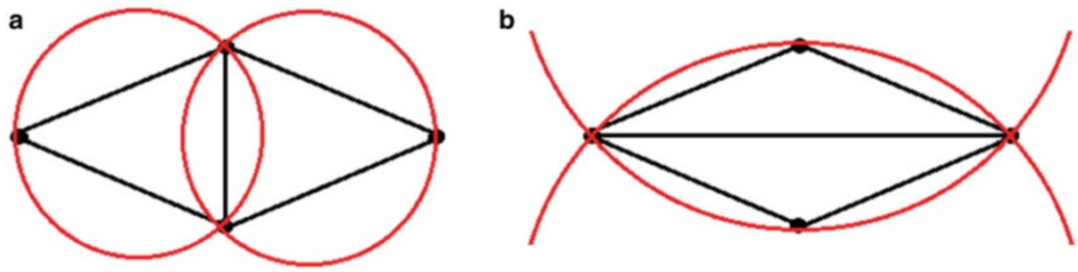
1. **Local empty circle**: A circumcircle is a unique circle passing through all vertices of a triangle in a Delaunay Triangulation $DT(V(n))$. This circle contains no other vertex from the set of vertices $V(n)$, (see Fig. 2) (van Kreveld 2014).

There are two levels to prove this property: (i) an edge e_{ij} is Delaunay if and only if there is not any vertex of the triangulation that falls inside the minimum circle that passes through both vertices of the edge. And, (ii) a triangle t_{ijk} is Delaunay if and only if there is not any vertex of the triangulation that falls inside the circumcircle of the triangle. A triangulation is Delaunay if and only if each edge or each triangle is Delaunay. Local Empty Property is shown in Fig. 2a, whereas Fig. 2b shown that the triangles does not satisfy the property.

Maximize the minimum angles: For each quadrilateral in Delaunay Triangulation *DT(V(n))*, two possible triangulations can be produced; the triangulation that maximizes the minimum of the six internal angles is the correct triangulation (see Fig. 3). It means, for each quadrilateral in a Delaunay Triangulation, there are two different triangulations with two triangles each one; let t_a and t_b be



Delaunay Triangulation, Fig. 1 Delaunay triangulation and voronoi (**a**) Delaunay Points (**b**) Delaunay Triangulation (**c**) Convex Hull (**d**) Delaunay Circuncircles (**e**) Delaunay Circumcenters (**f**) Voronoi Diagram



Delaunay Triangulation, Fig. 2 The local empty circle property (**a**) Delaunay Triangles (**b**) No Delaunay Triangles

triangulations. Let αt_a and αt_b be the smallest angle of the triangulations t_a and t_b, respectively. The Delaunay Triangulation includes the biggest angle between αt_a and αt_b (see Fig. 3b). For a Delaunay triangulation, Fig. 3a shows an invalid angles construction. A correct angle construction is depicted in Fig. 3b, which maximizes the minimum of the six internal angles (Mandal and Agarwal 2011).

Uniqueness: Delaunay Triangulation *DT(V(n))* is unique for a set of vertices *V(n)*, except for a set of four cocircular vertices (Khanimov and Sharir 2015) (see Fig. 4a). Similarly, Delaunay Tetrahedralization *DT(V(n))* is unique for a set of vertices *V(n)*, except for a set of five co-spherical vertices; for instance: a box (see Fig. 4b).

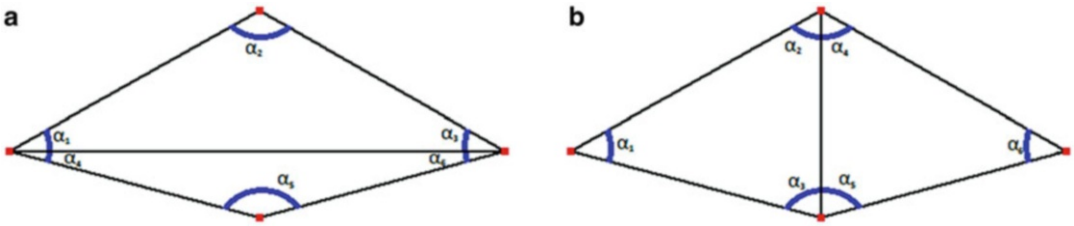
Those examples are based on regular shapes; however, irregular polygons or polyhedral can form a no-unique triangulation, for instance: uniform triangular prisms and uniform rectangular prisms, amongst others. Additionally, this exception can be extended to upper number of co-circular and co-spherical vertices.

Boundary: The borders of a Delaunay Triangulation *DT(V(n))* is the convex hull of *V(n)* (see Fig. 1c).

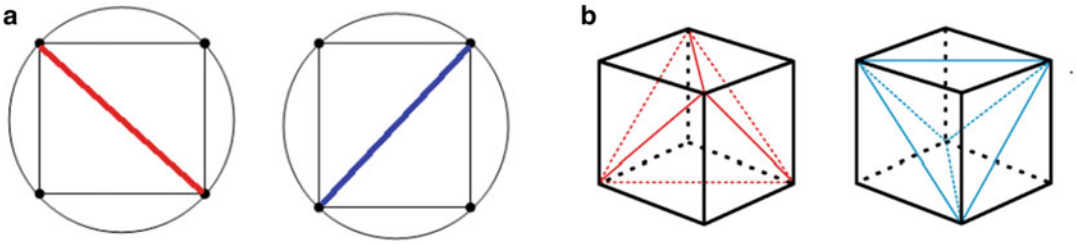
Quality in a Delaunay Triangulation

The following list shows a set of features that can ensure high quality in a Delaunay Triangulation (van Kreveld 2014):

- It does not have long edges. Long edges produce degeneracies; they are good in the boundary of the triangulation.
- It does not have triangles with both, short and long edges. The combination of long and short edges produces needles and caps.
- It does not have triangles with very small angles; these triangles can be needles or needle and caps.
- It does not have triangles with obtuse angles. Caps and needle and caps have these type of angles.
- It does not have vertices with high degree. A vertex connected to a high number of vertices is related with small angles, and, consequently, they are degeneracies.
- The combination of both long-short edges and small-obtuse angles produces degeneracies; it means needles and/or caps in two dimensions.



Delaunay Triangulation, Fig. 3 Bad and good angles in a Delaunay Triangulation (**a**) Bad angles in a Delaunay Triangulation (**b**) Good angles in a Delaunay Triangulation



Delaunay Triangulation, Fig. 4 No-unique Delaunay triangulation and tetrahedralization (**a**) No-unique Delaunay triangulation (**b**) No-unique Delaunay tetrahedralizations

Number of Triangles in a Delaunay Triangulation

According to van Kreveld (2014), a Delaunay Triangulation from n vertices – or a $DT(V(n))$ – have at least $n - 2$ and at most $2n - 5$ Delaunay triangles; moreover, it has at least $2n - 3$ and at most 3n − 6 Delaunay edges. According to de Berg et al. (2008) a Delaunay Triangulation from n vertices has $2n - 2 - k$ triangles and $3n - 3 - k$ edges, where k is the number of vertices in the Convex Hull.

Advantages of Delaunay Triangulation

The following list shows the main advantages of a Delaunay Triangulation (Mys 2004):

- It has elegant theoretical foundations and it has a wide range of application.
- The convex hull of the set of vertices is a part of a Delaunay Triangulation.
- The line connecting each point to its nearest neighbor must be in a Delaunay Triangulation.
- It produces a continuous surface, and it has an irregular connectivity.
- The construction does not depend on the starting point nor the dispersion of the points; it is predictable, repeatable, and equally easy (or hard) to construct for all applications.
- It is a method to cover a surface of a polygon using triangles.
- It is a common method to represent Triangulated Irregular Networks (TIN).
- It generates a mesh automatically.

Disadvantages of Delaunay Triangulation

Some disadvantages of working with Delaunay Triangulations include (Mys 2004):

- It does not maximize the minimum angle in three dimensions, even though, it does in two dimensions.
- When there is a mesh, the triangulation not always preserves it.
- It produces degeneracies in two and three dimensions.
- The type of tetrahedra with degeneracies in three dimensions is high (nine types) compared with degeneracies in two dimensions (three types).

Evaluation Tests

Even though Delaunay Triangulation has to fulfill the four properties described previously, the circumcircle criterion is the base of the evaluation of the structure; the circumcircle criterion forces the other properties.

The inCircle test verifies if a pair of adjacent triangles is Delaunay triangles; otherwise, the common edge between adjacent triangles has to be flipped to become a Delaunay triangles (Biniaz and Dastghaibyfard 2012). Similarly, the inSphere test proves the condition for a pair of tetrahedra; however, the change in the structure is not as straightforward as flipping an edge.

Let I be a set of indices and let $t_{ijk\ i,\ j,\ k \in I;\ i \neq j;\ i \neq k}$ be a triangle in counter-clockwise (CCW) orientation in the plane. Let C_{ijk} be the circumcircle of the triangle t_{ijk}. Let $v_l\ l \in I - \{i, j, k\}$ be a vertex. Then, the inCircle test is defined as follows:

$$\text{inCircle}\left(\tau_{ijk}, \vartheta_l\right) \begin{cases} = 0; & \vartheta_l \in C_{ijk}.\left(\vartheta_l \text{ falls on } C_{ijk}\right). \\ > 0; & \vartheta_l \text{ is outside } C_{ijk}. \\ < 0; & \vartheta_l \text{ is inside } C_{ijk}. \end{cases}$$

In general, the inCircle test can be simplified in an operation as follows:

$$\text{inCircle}\left(\tau_{ijk}, \vartheta_l\right) = \begin{vmatrix} x_i & y_i & x_i^2 + y_i^2 & 1 \\ x_j & y_j & x_j^2 + y_j^2 & 1 \\ x_k & y_k & x_k^2 + y_k^2 & 1 \\ x_l & y_l & x_l^2 + y_l^2 & 1 \end{vmatrix}$$

The orientation test verifies the order of the vertices that define the triangle, it means, to calculate a Delaunay Triangulation, a circumcircle test is required; however, the triangle has to have a positive orientation (counter-clockwise orientation). The orientation test is given by the following expression:

$$\text{orientation}\ \ 2D\left(\tau_{ijk}\right) \begin{cases} = 0; & \text{the vertices are collinear.} \\ > 0; & \text{the triangle } \tau_{ijk} \text{ has a positive (CCW) orientation.} \\ < 0; & \text{the triangle } \tau_{ijk} \text{ has a negative (CW) orientation.} \end{cases}$$

where

$$\text{orientation}\quad 2D(\tau_{ijk}) = \begin{vmatrix} x_i & y_i & 1 \\ x_j & y_j & 1 \\ x_k & y_k & 1 \end{vmatrix} = \begin{vmatrix} (x_i - x_k) & (y_i - y_k) \\ (x_j - x_k) & (y_j - y_k) \end{vmatrix}$$

Conclusion and Discussion

A Delaunay Triangulation is a triangle net in which every triangle satisfies the Circumcircle condition: the circumcircle of each triangle includes only the vertices of the triangle. In other words, the circumcircle does not contain any vertex of other triangles. If both the inCircle and the Orientation tests are the algorithmically mannered to probe this condition for all the triangles in a triangulation, then it can be labelled as Delaunay Triangulation.

Cross-References

- ▶ Constrained Edges and Delaunay Triangulation
- ▶ Modeling and Mesh Processing for Games
- ▶ Teaching Computer Graphics by Application
- ▶ UV Map Generation on Triangular Mesh

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Delone Tesselations

- ▶ Delaunay Triangulation

Delone Tessellations

▶ Constrained Edges and Delaunay Triangulation

Delone Triangulation

▶ Constrained Edges and Delaunay Triangulation
▶ Delaunay Triangulation

Depth of Field

▶ 3D-Rendered Images and Their Application in the Interior Design

Design Framework for Learning to Support Industry 4.0

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Synonyms

Education model; Education pedagogy; Fourth Industrial Revolution; Industry 4.0; Learning analytics; Learning framework

Definition

Learning analytics is defined as the measurement, gathering, analysis, and reporting of data about learners and their environments, for the aim of understanding and improving learning process and the contexts in which learning occurs (Siemens and Baker 2012).

Introduction

The technology era has been growing very quickly, and it leads to the new industrial revolution which is also known as Industry 4.0. The inventions of new technologies like virtual reality, 3D printer, and the Internet have greatly influenced different sectors of the world economy. The digital technology sector in the UK has grown tremendously despite the economic crisis in 2008. Based on the Tech Nation Report in 2018, the UK digital tech sector is worth nearly £184bn to the economy, a rise from £170bn in 2016 (Cahill et al. 2018). However, Job Market Report 2017 has shown that the growth of the digital economy and the emergence of new technologies has led to skills shortages and increased demand for graduates with the right qualifications (Dice 2017).

These advancements led educational institutions to be interested in possible changes that could involve the changes in curriculum which can help prepare the students to face the industry after they graduate. Industry 4.0 implies that the world is globalized, automatized, virtualized, networked, and flexible. This section briefly maps the education with industrial revolution. It is believed that education has to follow the pace of industrial revolution. The following section maps the education with industrial revolutions.

Mapping Education with Industrial Revolutions

The evolution of the industry which progresses from First Industrial Revolution (Industry 1.0) to Fourth Industrial Revolution (Industry 4.0) can be used as a sign to show how important it is that education should also be developed and evolved from Education 1.0 towards Education 4.0. The industry has undergone a process of digital transformation which exposes the education to challenges and opportunities of meeting the needs of the fast-growing industry. The changes in the industry development (industrial revolution) will also cause changes to the development of education (education revolution) which means certain

skills are required which are not exactly the same as the skills that were required before. Therefore, the current and future education structure should not only focus on training knowledge-based skill labor but also emphasize on cultivating innovative talent to meet the current demand of the industry.

Before and During Industry 1.0: Before the industrial revolution, education started by focusing only on teaching the elite classes and educating boys. Education was taught informally before it transformed by focusing on scientific research. Most education started with the dominance of religions. The industrial revolution caused widespread change in all aspects of society. Therefore, many motivated individuals could easily take advantage of the many economic opportunities of the situation. Research study also added in that modern economic growth depends on the growth of useful knowledge (Tang and Werner 2017). Therefore, this emphasizes the importance of gaining knowledge through education. Industry 1.0 marked the beginning of industrialization which led to the demand for mass education, education for ordinary people especially from lower classes. This was the time when there was a demand in the workforce fit for the industrial sector. More schools were built and the new concept "free education" was introduced during that period (Robinson 2011).

Industry 2.0: This industry began with electrification cycle when electricity became the primary source of power since twentieth century (Hughes 1993). During the Second Industrial Revolution (Industry 2.0), the graduates were viewed as ill-prepared line assembly workers as the inventions of machines helped a lot in mass production. Skill undoubtedly played an important role in technological innovation and adoption (Greenwood 1997). People did not know how to work efficiently until Frederick Taylor and Henry Ford proposed workplace methods and just-in-time and lean manufacturing principles to optimize the workforce and improve their quality and output.

Industry 3.0: It is also known as the information revolution or the digital revolution. This is the era of production automation when there is an increasing use of electronics in industrial process and commerce and computer-programmed electronic devices replaced the electric-based production machines (Khan 1987). The Third Industrial Revolution (Industry 3.0) initiated the telecommunication industry, and this implies that as communication became easier, people could access and create content anywhere, any time. However, there are some countries that are still applying the approach used in Education 1.0 which only involves one-way learning process (where students are passive and they are instilled with the most essential or basic academic knowledge and skills and character development (Petrina 1998; Gerstein 2014) and Education 2.0 (an approach used where students are active learners and gain knowledge by formulating and solving their own problems (McWilliam 2009; Gerstein 2014), while other countries have started developing new education models that reflect the increased use of technology and enable increasingly flexible, experimental, and fairer learning environments which lead to the introduction of the new era, Education 3.0. Students started sharing their knowledge with peers who have different skills and levels of knowledge to co-create new knowledge. This shows that technology was used to assist students' learning process and helped them in shaping the content, location, and ways in which they learn.

Industry 4.0: Due to the new industry era, the technology grows rapidly, and there are so many new inventions. However, Lortie (2002) argued that at the beginning of twenty-first century, the education does not change at a rapid pace as the structures of education are still the same as in the twentieth century. The existence of sensors and IOT can actually indicate an early sign of the use of wearables-assisted teaching, learning, and training devices. Recently, there is a limited number of research studies that use smartphones and sensors to study the factors that affect the academic performance of students. It was found out that there are many other factors that affect their performance, and this leads to complexity in research. As Education 4.0 indicates the world is complex, standardization approach that was used to be applied in Education 1.0 had to be eradicated. It is also added that standardized learning methods cannot deliver what the current and

future education needs when it comes to cope with complexity (Wallner 2012). This is true because everyone is different and unique, and everyone can stand out if one can manage to discover his/her own method of effective learning. This can be done through the assistance of current technologies invented in Industry 4.0.

The comparison between education evolutions and industry revolution are summarized in Table 1. The table shows that the technology advances rapidly, revolving from Industry 1.0 to the current era Industry 4.0, but the old educational models used in previous eras are still being applied in the fast-moving technology era. This implies that there is a gap between each education era and technology era. Education is moving slower than the industry. It has to move faster in order to catch up with the fast-growing demands, and in fact, it should be faster than the industry so that the supply of skills and talents can match with the demand of the industry.

Different Types of Analytics in Education

Learning analytics (LA) is a powerful tool which gives practical insights on the variables in the datasets. It focuses on the educational challenge in optimizing opportunities for learning. Siemens has first defined LA in his blog post as the use of intelligent data, learner-produced data, and analysis models to discover information and social connections and to predict and advise on learning (Siemens and Baker 2012). The definition was then refined in international conferences, and the Society for Learning Analytics Research (SOLAR) then defined LA as the measurement, gathering, analysis, and reporting of data about learners and their environments, for the aim of understanding and improving learning process and the contexts in which learning occurs.

LA is a new research field that is often associated with technology-enhanced learning. The improvement of teaching and learning using LA has led to the use of the term "Big Data" in the education field. Moreover, in this context, big data in education which is also known as educational data is what drives new methods to be used in LA (Siemens and Baker 2012). They stated that the specific features of data contributed to the different methods are playing a prominent role in educational data mining (EDM) and LA. LA is an emerging research field that studies strategies on how to enhance student and faculty performance,

Design Framework for Learning to Support Industry 4.0, Table 1 Summary of comparison between industrial revolution and education evolution

Types of revolution (Age)	Before eighteenth century (Agricultural Age)	Eighteenth century (Industrial Age)	Nineteenth century (Knowledge Age)	Twentieth century (Digital Age)	Twenty-first century (Connected World)
Industry	Before Industry 1.0	1.0 (Mechanization)	2.0 (Electrification cycle)	3.0 (Automation)	4.0 (Smart automation)
The views of industry on graduates	Industrial Age has not started yet	Assembly line workers	As ill-prepared assembly line workers	As co-workers	Lack of skills and talents as required (Evangelinos and Holley 2016; Manpower Group 2018)
Education	1.0	1.0 2.0 (Ideally)	1.0 2.0 3.0 (Ideally)	1.0 2.0 3.0 4.0 (Ideally)	1.0 2.0 3.0 4.0 (Still emerging)
Implication	–	There is a gap between each education era and technology era. Education is moving slower than the industry. It has to move faster in order to catch up with the fast-growing demands, and in fact, it should be faster than the industry so that the supply of skills and talents can match with the demand of the industry			

how to identify the needs of struggling learners, how to improve accuracy of prediction, etc. (Larusson and White 2014). In addition, LA helps to explore in what areas of the curriculum that can be improved. This complies with the definition of LA which is "the interpretation of a wide range of data produced by and gathered on behalf of students in order to assess academic progress, predict future performance, and spot potential issues" (Liñán and Pérez 2015). It can be clearly seen that there are different definitions provided for the term LA. However, these definitions focus on transforming educational data into actionable data to help improve the learning process.

The term academic analytics (AA) is always interchangeably used with LA. However, there is a distinction between these two terms. In order to identify the difference between LA and AA, it is vital to know the origin of AA. This term was first used to describe the business intelligence application tools and practices in higher education (Chatti et al. 2012). The authors further refer business intelligence to an analytics tool that involves the processes like collecting, storing, analyzing, and providing access to data to help enterprise users make informed business decisions. Therefore, to derive the definition from business intelligence and to place it in educational context, it can be said that AA is more emphasized on political or economic aspect of education as it helps to improve learning opportunities and educational results at institutional, regional, and international levels (Ferguson 2012; Daniel 2015). The author further added that AA benefits funders, administrators, marketing, government, and education authorities (Ferguson 2012). Like LA, AA also analyzes enormous data sets with statistical techniques and predictive modelling, but the purpose is to help in decision-making unlike LA which is used to help in improving learning process (Daniel 2015).

To narrow the definition down, AA focuses on student retention and graduation rates that actually affect the institutional level (Campbell et al. 2007). Issues of detecting students that are at risk are often related to AA (Chatti et al. 2012). In AA research, operational activities relevant to academic modules and student strengths and weakness can be identified and appropriately rectified.

Educational data mining (EDM) is a field which is often used together with LA as they present similar notions. However, both focus on different types of challenges. EDM deals more with the technical challenge while LA focuses more on educational challenge. EDM stresses on extracting value from an enormous pool of educational data. The phrase "data mining" in EDM has already suggested that it is very technical. It is concerned with developing methods to explore the unique types of educational data and identify the patterns in order to have a better understanding of the students and the environments in where they learn (Romero et al. 2010).

Quite similar to LA, the objective of EDM is to analyze the data to understand how students learn and to make predictions based on the analysis. Unlike EDM, LA further includes other methods, such as statistical and visualization tools or social network analysis (SNA) techniques and puts them into practice for studying their actual effectiveness on the improvement of teaching and learning. EDM focuses more on classification, association, and other data mining techniques in analyzing data.

It is hard to separate LA and adaptive learning analytics (ALA) because they both foster technology-supported, learner-centered education. LA is often associated with adaptation. Adaptation means making adjustments in a particular environment to accommodate the individual differences. Adaptivity and adaptability are the common terms that are related to adaptation. Adaptivity refers to a process where the data about learner is used in a system controlled way, whereas adaptability means the system supports end-user modifiability providing student control (Mavroudi et al. 2018).

A common idea behind those adaptive educational systems is that, based on the information about the learner and the current context, an appropriate adaptation method should be chosen to adapt the presentation of the course material to the individual learner. ALA focuses on learner modeling as the core for achieving adaptive and

personalized learning environments, which will be able to consider the heterogeneous needs of learners and provide them with tailored learning experience suited for their unique needs.

Motivation to Learn

Conventional educational pedagogy which adheres to the "one-size-fits-all" approach characteristic of traditional education systems can no longer be used in this fast-changing era. The motivation and capacity to learn independently is crucial to personalization which is the pedagogy for Education 4.0, because it reduces dependence on the teacher and traditional class-based styles of instruction. In order to produce individuals that thirst for learning, self-reflection and motivation are required to be reinforced (Leadbeater 2008). In addition, an education model will tend to undermine the possibility of independent learning and developing skills if there is a lack of motivation, because it can lead to a decrease in the levels of learning (Saveedra and Opfer 2012). As it is important to foster motivation for independent learning, research emphasizes the importance of the teacher's role in motivating learners and finding ways for them to build intrinsic motivation (Meyer et al. 2010). There are a few theories which contribute to the learning motivation of learners. Social cognitive theory reflects the importance of the relationship between behavior, environment factor, and personal factor as these three factors are interconnected, and it is also known as cause and effect relationship (Bandura 1989). This theory also depicts what caused the people to behave certain ways and provides basic interventions (Bandura 1997). It is also found out that environment factor can influence people and can be divided into social environment (family and friends) and physical environment (comforts) (Bandura 1997). These factors are also known to affect the students' learning process.

Research also found that the challenge, curiosity, control, and fantasy are the key factors to trigger up intrinsic motivation (Ryan and Deci 2000). These factors can boost will power and positive attitude in pursuing education. Moreover, Lepper et al. (2005) and Pérez-López and Contero (2013) claim that academic achievement also influences the intrinsic motivation. Attitude in learning is considered very essential as it influences the academic achievement (Cai et al. 2017).

Big Data Analytics, Academic Analytics, Learning Analytics Process

Big data analytics (BDA) in the education context is also known as LA. LA is more specific and only used in educational context, whereas BDA can be applied in different sectors. Thus, the stages involved in BDA are a bit different from the stages involved in LA and AA.

Data Collection and Pre-processing: The first stage in BDA, LA, and AA processes involves collecting a vast amount of data. In LA and AA, data are collected from the various educational environments and systems, whereas data in Big Data can be collected from different sources and they are not necessarily sourced from the educational context (Daniel 2015). These data often come in various attributes and formats. Researchers need to first determine the format of data, the amount of data to be used, and choose techniques to retrieve that data (Campbell et al. 2007).

As the collected data are available in vast amount, data have to be managed and pre-processed. These data are analyzed to discover interesting and useful patterns that can be used to retrieve useful information. In LA process, data is transformed into suitable format by using different methods such as data cleaning, data integration, data transformation, data reduction, data modelling, user and session identification, and path completion.

Statistics tools are recommended to be used during this stage to handle large quantities of data (Chatti et al. 2012). This stage is vital when it comes to computing the description for the data as it gives the end users a reflection on what has happened.

Analytics and Actions: The next stage of the process in LA, AA, and BDA is known as

analytics. Each technique used to analyze data depends on the type of selected data and the goal of the research. Different LA techniques like data mining techniques, statistics and mathematics, text mining, semantics and linguistic analysis, visualization social network analysis, qualitative analysis, and gamification can be applied to analyze and explore the data in order to discover hidden patterns or insights that can help to provide a more effective learning experience (Khalil and Ebner 2016).

The following stage in all three LA, AA, and BDA processes includes actions on the information that have been analyzed such as monitoring, analysis, prediction, intervention, assessment, adaptation, personalization, recommendation, and reflection. Taking actions is the primary aim of the whole analytics process (Daniel 2015) which also means answering questions that leads to the stage of data collection (Campbell et al. 2007). A model is built at the end of this stage and improvements can be seen as the result. These actions can be executed either manually or automatically which may include linking, connecting correlating different data sets to be able to obtain insight that is supposed to be conveyed by these data. In LA process, actions can be prescriptive as it can help students to be successful (Khalil and Ebner 2016). On the other hand, the complexity of BDA occurs when the management and the analysis of the largely diverse data becomes a complex process (Daniel 2015).

Refining/Post-processing/Visualization: The last stage of LA and AA processes is a bit different from the last step in BDA process. The last step in the BDA process actually involves presenting the analyzed data into an interpretable and integrated information to help inform the decision of stakeholders (Daniel 2015), whereas the last stage of LA and AA process includes continuous improvement of analytics exercise (Chatti et al. 2012; Campbell et al. 2007). This stage takes place when the actions taken in the previous stage and the processed results are evaluated. As stated in Chatti et al. (2012), this stage may include compiling new data from additional data sources, improving the data set, determining new criteria required for the new iteration, identifying new predictors or criteria, modifying the variables of analysis, or selecting a new analytics method.

Existing Frameworks

LA Framework: Previous literature studies have proposed different frameworks for LA. A reference model for LA is proposed based on four dimensions, namely, data and environments (what?), stakeholders (who?), objectives (why?), and methods (how?) (Chatti et al. 2012). Based on the reference model, various challenges and research opportunities are suggested by reviewing recent publications on LA and its related fields based on the proposed reference model. Findings showed that (1) centralized web-based learning systems represent the most widely used data source for LA, (2) most of the current LA applications are oriented toward intelligent tutors or researchers/system designers, (3) the most commonly applied objectives are adaptation and monitoring/analysis, and (4) the most frequently used LA techniques are classification and prediction.

The authors that proposed the generic model actually extended the reference model by adding two extra dimensions which are the external limitations and internal limitations (Greller and Drachsler 2012). The authors also argued that the critical problem zones, and some potential dangers to the beneficial exploitation of educational data, should be explored in order to provide a more comprehensive and useful guide for setting up LA services to support the learners, teachers, and institutions.

While the other proposed frameworks are only focusing on LA generally, a different framework that combines adaptation and LA was proposed and considered the same dimensions as the previously mentioned frameworks (what, who, why, and how) but added two more dimensions which are when and where (McWilliam 2009). This framework suggested the following points: (1) key data related to the context and tools used, (2) objectives, (3) stakeholders, (4) application area and context, (5) time-related aspects, and (6) use of LA and adaptation.

DigComp Framework and EntreComp Framework by European Commission: DigComp framework is a framework that consists of five dimensions which are competence areas, competences, proficiency level, examples of knowledge skills and attitudes, and example of applicability to purpose (Ferrari 2013). The competence areas which include information, communication, content creation, safety, and problem-solving are the main components of this framework (Vuorikari et al. 2016). This framework is being applied in the education sectors and proven to be helpful in investigating the digital attitudes, skills, and development needs of healthcare students (Evangelinos and Holley 2016). Besides that, this framework is also used to examine factors predicting lower secondary school students' digital competence (Hatlevik et al. 2015). This framework also covers three different proficiency levels and specified indicators for the development of each digital competence.

Similar to DigComp framework, EntreComp framework is also developed by the European Commission to establish a bridge between the world of education and employment and to be used as a reference by any initiative which aims to encourage entrepreneurial learning. Like DigComp framework, EntreComp has competence areas which are ideas and opportunities, resources, and putting strategies into action. Each area includes 5 competences which sums up to 15 competences along an eight-level progression model (Bacigalupo et al. 2016).

Issues Concerned with Existing Framework: There are several concerns that should be taken into consideration when it comes to designing LA. Researchers will also need to investigate problems faced by learners in different environments and what success looks like from the perspective of learners (Ferguson 2012). The analytics process should be transparent so that the learners can respond with feedback that can be used to refine the model and to be able to see how their data are used. The other researchers also added that LA can only be effective if the outcome can generate insights into the pedagogical didactic consequences for both learning and teaching practice (Ferguson 2012; Van den Bogaard and De Vries 2017). LA should be designed based on theoretical models and needs of students should be well understood. Feedback of LA is essential for learning, and it is important to identify which kind of feedback is suitable for which kind of student.

Feedback of LA leads to the question on the quality assurance of LA. The quality assurance of LA services is questioned as they might only meet the expectations of certain stakeholders (e.g., managers) while overlooking those who are the most important (e.g., students) (Liñán and Pérez 2015).

Although DigComp framework is being widely used for strategic support for policy making by European Union member, none has displayed strategies that can be used with different stakeholders to develop digital competence especially in the aspect of problem-solving (Balula 2016). The author also said that it is vital to highlight that DigComp framework is descriptive rather than prescriptive, and therefore, this framework is always prone to be revised and updated, and each update takes a long time as it involves many stakeholders to reach a consensus. EntreComp framework has not yet been adapted to or tested in real settings, and it is a result of a robust research methodology which involves experts' consultation and input. Therefore, it will also take time for the framework to be updated. A framework that suits education and industry needs should be able to be updated quickly to suit the needs as education evolution has been in a slow pace while technology is growing very rapidly (Table 2).

Conclusion and Discussion

There are studies on LA framework, but there is a limited number of studies (prior to our knowledge) focusing on students' motivation in learning in the design of LA framework. Attitude is important because the quality of framework will not even matter if the students do not have motivation to learn. Therefore, the design of the framework should start from focusing on the learners' motivation to learn (attitude) before focusing on other

Design Framework for Learning to Support Industry 4.0, Table 2 Summary on the strengths and limitations of different frameworks

Types of framework	Strengths	Limitations
LA framework	Provide a more comprehensive and useful guide for setting up LA services to support the learners, teachers, and institutions which is believed to cover all related aspects: (1) key data related to the context and tools used, (2) objectives (3) stakeholders, (4) application area and context, (5) time-related aspects, and (6) use of LA and adaptation	Quality assurance (only meet the expectations of certain stakeholders)
EntreComp framework	Used as a reference by any initiative which aims to encourage entrepreneurial learning	Has not yet been adapted to or tested in real settings and it is a result of a robust research methodology which involves experts' consultation and input
DigComp framework	Helpful in investigating the digital attitudes, skills, and development needs of students Used to examine factors predicting students' digital competence	This framework is always prone to be revised and updated, and each update takes a long time as it involves many stakeholders to reach a consensus

elements to help improve their learning process. To date, the education analytics such as LA, EDM, and so on have focused predominantly on analyzing data systematically gathered in educational settings, which at the tertiary level includes factors of prior academic performance, demographic data, such as age and gender, and data gathered by logs recording student behavior in online learning environments. Although the initial results in the literature studies are encouraging across a variety of analysis techniques, there is scope for more research investigating the contribution of additional data such as psychometric data that could be gathered by tertiary education providers, as well as how this data should be modelled to enhance the current algorithmic models of student learning, and offer actionable feedback on the learning process. Therefore, in order to address this issue, it is important to understand the factors that affect the students' learning progress so that more interventions can be done to help to solve the problems of talent shortage.

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Design of Alienation in Video Games

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Synonyms

Alienation; Defamiliarization; Mechanics

Definition

In this entry, it is proposed that game designers can utilize hardware systems and the structure of gameplay to highlight a game's formal characteristics for "alienation" effect. Drawing inspiration from Bertolt Brecht's notion of "Verfremdungseffekt," or alienation effect, and using MDA framework (Hunicke et al. 2004), traits between alienation effect and techniques used in specific video games are analyzed to define what this article calls as "gamic alienation." Through the reading of gameplay moments in various games that make use of gamic alienation, a continuum that consists of two important concepts for creating this effect is identified: hardware signifiers and software signifiers. Throughout the entry, it is discussed how the use of these signifiers is implemented in a range of video games, from triple-A games such as *Metal Gear Solid* to indie games such as *DLC Quest*.

Introduction

In the area of video games, the player has similarities with the audience of a theatre play. The player is an active agent of the software, in which she provides the input, but concurrently, she is also the audience of play. The participatory structure of video games allows the players to become spectators of their own engagement with the system. This cyclic process of input and output can lead to changes in player's approach and behavior.

Playwright Bertolt Brecht argues that "The modern theatre mustn't be judged by its success in satisfying the audience's habits but by its success in transforming them" (Brecht 1964). A term coined by him, "alienation" is an effect that intends to disrupt the performative characteristic of a play to render the act of performance abnormal by underlining the conventions of the play, rather than its content. The goal is to raise self-awareness among the audience, make the theatrical devices visible, and as Brecht states, change the way an audience engages with a text.

According to Brecht, theater should attempt to stimulate social change by being provocative and didactic and also it should address their reason rather than their senses (Brecht 1991). Brechtian theater aims to break down the illusion of reality with the alienation effect which makes the audience critically aware of itself as audience and of the play as artifice. The audience is encouraged to observe their own daily circumstances in a new light.

When applied to video games, the concept of alienation can further enhance the quality of an audience's interaction with the medium (Dunne 2014). However, the studies between alienation effect and video games are not new to the field. For instance, it is known that horror game genre can use this effect to defamiliarize the player from the game; but with rare exceptions, the purpose is not to urge self-reflexivity, instead to convey specific aesthetic effects (Kirkland 2007). Therefore, it is important to acknowledge that the use of alienation effect may not always lead to critical play behavior.

Technical glitches, lags, and bugs can also be considered as alienating effects (Galloway 2006). In addition, loading screens or in-game interfaces such as pause screen or saving slots can be interpreted as mechanical systems that detract the player from core gameplay (Dunne 2014). However, that analysis is beyond the scope of this entry. It is important to acknowledge that this article examines "gamic alienation" that is intentionally constructed by game designers in order to break player's engagement with a game.

In this entry, the term alienation effect is not necessarily used in the political (i.e., Marxist

aesthetics) sense used by Brecht in his discussion of epic theatre. However, an emphasis is placed on the critical attitude that is aimed to encourage the audience (in this context, players) to adopt. In particular, formal game structures that are in the pursuit of inducing reflection in terms of aesthetics and refer to its own mechanics are highlighted. In that regard, this entry uses a pre-existing framework Mechanics, Dynamics, and Aesthetics (which will be referred to as "MDA") and by mechanics, "particular components of the game, at the level of data representation and algorithms" are meant (Hunicke et al. 2004). Aesthetics are defined as "the desirable emotional responses evoked in the player, when she interacts with the game system" and dynamics describe "the runtime behavior of the mechanics acting on player inputs and each others' outputs over time" (Hunicke et al. 2004). Thus, "gamic alienation" can be described as the technique in which the output of gameplay points out the mechanics of the game, and it is intrinsically designed for the purpose of encouraging reflection among players.

The rest of the entry is structured as follows. The terminology behind MDA framework in relation to "gamic alienation" is further explained. Then, two categories, namely, hardware signifiers and software signifiers, that demonstrate the ways game designers use alienation techniques are analyzed. These categories are explored with different examples. Finally, the entry shares its concluding marks and ends with suggestions for other works in future.

Mechanics, Dynamics and Aesthetics in Relation to Gamic Alienation

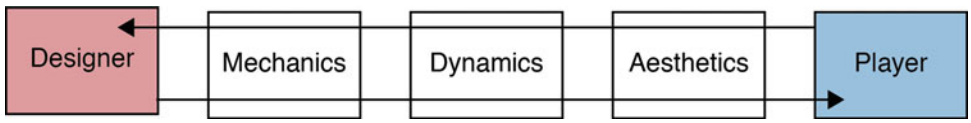
MDA framework provides a detailed terminology to analyze how each component influence designer's choices and influences player's experience. One of the objectives of MDA framework is to work as a bridge to close the gap "between game design and development, game criticism, and technical game research" (Hunicke et al. 2004).

In MDA, mechanics refer to formal aspects of game design, namely, set of rules, for instance, AI behavior, physics, winning condition, health system, etc., Dynamics is about how the game responds to actions player take during gameplay such as commanding an army, controlling a gang, fighting enemies, or simply navigational stuff like walking and running. All the rules have to work together and give proper feedback to the player. Aesthetics, on the other hand, defines player's experience and main interests in the game. For example, a player can start playing a game to get under the skin of a superhero, to beat a friend's high-score in a competitive game, or to enter a fantasy world.

The mechanics work in concert to make the dynamics, which generate the game's aesthetics (see Fig. 1). Game designers and players meet a game from the opposite sides. At a fundamental level, players start to experience a game through aesthetics and game designers initially construct their ideas with the mechanics, which in turn translates to player experience.

Similar to a playwright, a game designer can create the set of rules but has a little amount of control over how the act of play will be enacted by the players. In that regard, MDA framework shows how a game designer can affect player's experience, but it is the player who crafts the gameplay experience.

A player needs to start with the experience crafted by the game in order to understand the mechanics of the game. And mechanics are built on top of two layers: hardware and software (see Fig. 2). As it is demonstrated in the following sections, video games can make different use of mechanics with hardware signifiers and software signifiers in order to invoke "gamic alienation."



Design of Alienation in Video Games, Fig. 1 MDA as seen by designer and player

In the next section, the first part of the continuum, *hardware signifiers*, is discussed (Fig. 3).

Hardware Signifiers

In first *Metal Gear Solid (MGS)* (1997), the game features a boss battle with an enemy called Psycho Mantis. No details about the character are presented before the encounter, except the clue in his name. When the player first confronts him, a cutscene intervenes the gameplay, and during that cutscene, Psycho Mantis starts to comment on the save files of the player, depending on which system the game is being played. If *MGS* (1997) is played on PlayStation, then Psycho Mantis will comment on Konami-based save files ("You like Castlevania, don't you?"). If it is played on Nintendo (which is called as *Metal Gear Solid: The Twin Snakes* (2004) and is the remake of the original game), then there are other specific games he is able to recognize, which are *Castlevania: Symphony of the Night* (1997), *Super Mario Bros.* (1985), *and Eternal Darkness: Sanity's Requiem* (2002). If there is no save file that the system can detect, Psycho Mantis says ("Your memory is empty"). Moreover, Psycho Mantis also comments on how many times the player has saved the game until that point of gameplay or how he is acting towards enemies in the game (e.g., using violence or stealth). After that, he orders the player to put his controller on the floor and he starts to move the controller by using vibration feature.

When this sequence is over, the player starts to fight with Psycho Mantis. During the fight, Psycho Mantis can lift all the items and objects in the room and throw them to the player's avatar, Solid Snake. All the attempts by the player to hurt Psycho Mantis are failed and the player loses all the control over the controller because of Mantis's psychokinetic abilities.

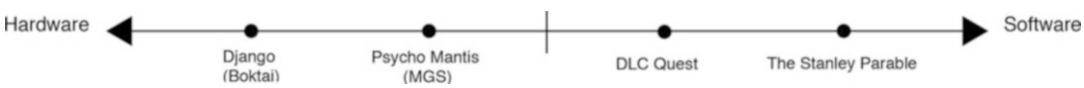
The only way player can defeat Psycho Mantis is to unplug the controller's cable from the console's port and plug into the second one. By switching the controller's port, player regains its control over Solid Snake and since Psycho Mantis cannot read her mind anymore, the player can easily beat him.

This instance of gameplay moment shows how mechanics can be used to create a "gamic alienation." Before presenting the actual challenge, an in-game character refers to non-in-game elements such as save data from other games, or explicit reference to the controller. This gameplay moment occurs at a point where player is already familiar with aesthetics and dynamics of the game, and by using hardware signifiers, the mechanics in the game encourage the player to question mechanics themselves and therefore, it requires a critical reflection of the medium. The game defamiliarizes player from the game itself.

This kind of alienation that makes use of hardware signifiers is also used in Nintendo DS game, *The Legend of Zelda: Phantom of Hourglass* (2007). One specific puzzle involves critical thinking and requires the self-awareness of the player in order to overcome the challenge. As it is known to all, Nintendo DS features two split screens. And in this puzzle, the player needs to press the seal on a map from upper-screen to bottom-screen. The player needs to close her DS and open it again in order to complete the task.

Another prominent example that makes use of this approach is *Boktai: The Sun is in Your Hand* (2003). A Game Boy Advance title directed by the designer of *Metal Gear Solid* (1997), Hideo Kojima, *Boktai: The Sun is in Your Hand* (2003)

Design of Alienation in Video Games, Fig. 2 The relationship between hardware, software and mechanics



Design of Alienation in Video Games, Fig. 3 A continuum to show the categorization of gamic alienation

introduces a vampire hunter called *Django* and the game asks the player to be outdoors and get sunlight. The game asks this because the game's cartridge included a daylight sensor (Plunkett 2017) and you can save the energy from sunlight in batteries and later, *Django* can use that energy for his weapon to play against his enemies in the dark. *Boktai: The Sun is in Your Hand* (2003) is simply another title that induces reflection on the game's medium. Even though the game explicitly mentions that only sunlight can be used to save energy, some players found out creative solutions to get sunlight without going outdoors (Plunkett 2017). This is just another proof that raising a critical approach via mechanics can lead to unexpected gameplay styles and offer different aesthetics.

Software Signifiers

In the previous section, the use of hardware signifiers within the context of "gamic alienation" is examined. The three titles that are covered demonstrated how mechanics can be used to refer to physical space outside game's world.

In this section, different approaches to create alienation with the use of software signifiers are identified, in particular through the reading of *The Stanley Parable* (2013). Unlike the examples that use hardware signifiers, *The Stanley Parable* (2013) has been selected since it provides a wide range of "gamic alienation" moments that are distinct than the ones already analyzed. In no particular order, these approaches created with the use of software signifiers can be listed as:

- Conflict between narrator's comment and player's actions
- Demonstration of game's production process
- Reference to other game worlds

Conflict Between Narrator's Comment and Player's Actions

Stanley Parable is an indie game that includes a voice-over narrator who tries to tell a story by commenting on the actions and the decisions taken by player. Unexpectedly, the game plays with narrative conventions in so far that in most of the cases, the descriptions of the narrator conflicts actions taken by the player.

The game starts in an office room and in the very beginning, the player finds himself in a room with two doors. The narrator tells that "When Stanley came to a set of two open doors, he entered the door on his left."

Evidently, it depends on the player to choose which door she wants to enter. Choosing right door breaks the narrative progression of narrator and tells the player to return back to her path. Otherwise, narration continues smoothly until to a certain point where something that narrator has not planned appears.

The conflict between narrator's comments and player's action is the first and major type of alienation effect used in *The Stanley Parable* (2013).

Demonstration of Game's Production Process

The second type of alienation in the game is about showing the scenes and assets behind the game's production process. There is one particular part in the game where a female narrator takes over and teleports Stanley to a museum so that he can explore the game's production process. In this museum level, player can see the credits, content from different endings, scale model of levels in the game, the details about Steam's Greenlight process, and the assets that was removed in the final version of the game. But this is rather an interesting use of alienation as these assets take place in the very final build of the game, even though they are claimed to have been removed. For example, in one of the rooms in the museum, player sees "Warzone" scene and it is written that:

> Early in development, we designed an ending where Stanley would end up on a battlefield fighting aliens. The action game would become sentient and would wage war against the Narrator. We realized shortly after starting to build it that it was far too jokey and on-the-no for the tone of the game.

Thus, players are essentially playing a level within the game where they are able to see behind the scenes of development and understand the

intentions of game designers. This level suspends the gameplay and playfully refers to its own artificiality by using software signifiers to create alienation effect.

Reference to Other Game Worlds

The third type of "gamic alienation" through the use of software signifiers can be described with the references to other game worlds. These references can either be visual analogies to game environments of other titles or replication of mechanics from other games.

The Stanley Parable (2013) accommodates levels from other titles such as *Minecraft* (2009) and *Portal* (2007). There is a special ending in the game where narrator gives up on player and instead of convincing Stanley to follow his orders, he loads example levels from *Minecraft* (2009) and *Portal* (2007), respectively.

Another title that serves as a good example to explain this category is *DLC Quest* (2012). The title of the game refers to Downloadable Content (DLC), and it is a satirical critique of games that promote DLC packages. *DLC Quest* (2012) does not incorporate the mechanics from other titles literally but alludes their implications within its own mechanics.

DLC Quest (2012) also includes DLCs, but unlike other games, DLCs in this game can be purchased freely. The game is based on a 2d platformer genre, but it starts without any animation or sound. A merchant in the first level is met, reminiscent of the ones in an RPG game, and he informs the player that he needs to collect coins to buy in-game components like sound, animation, enemies, and weapons. Obviously, the game aims to critically refer latest industry trends for monetization models used by triple-A studios.

Presenting game's essential components such as sound and animation as a separately sold DLC, required to be bought by the player to further progress in the game, elevates its meaning to a critical level. Hence, the player is considered as an active agent who has a background knowledge of the DLC issues. Although it is possible to play the game without understanding the self-referential messages implied through mechanics, it plays an important role to perceive software signifiers.

Conclusion

In this entry, the concept of alienation is examined through the reading of several games. The article initially draws inspiration from Brecht's alienation effect, but it is primarily based on MDA framework. The entry identifies two important terms: hardware signifiers and software signifiers. And games can be placed differently on this continuum.

The most important conclusion of gamic alienation is the games that use this effect want their players to take a critical stance towards the game itself and become self-aware. This is done by changing player's focus from the avatar's actions and events taking place on the screen and by drawing attention to game's mechanics, including the hardware that the game software is running on.

Nonetheless, there are issues that need to be addressed in a future research. First important point is that the use of gamic alienation does not always lead to critical play. Regardless of game designer's clear intentions, the gameplay experience can lead to hours of frustration among players, and it can eventually cause them to leave the game. It is worth analyzing why this issue occurs and how it can be addressed.

Secondly, the parameters to determine a game's place on the hardware/software signifier continuum are not clear. Further analysis is necessary to formulate the attributes of a game in the pursuit of improving continuum's structure. New categories can be introduced if necessary.

The results listed above are only limited to the reading of few games. As such, they are not exhaustive and therefore requires validation through empirical research and examination of a wider range of video games. In addition, new emerging technologies such as VR and AR provide more opportunities for using alienation effect in different ways. This entry shows the scarcity of good examples that make use of hardware

signifiers for creating gamic alienation. The findings in this entry can provide some insights on alienation concept and potentially inspire game designers to create new alienation effects.

Lastly, instead of purely focusing on immersion, video games can embrace the technical attributes it inherits as a medium and incorporate them to provide enriching play experiences. Just as Brecht wanted to encourage the audience to question the events on the stage, why don't the video games motivate players to be self-aware and take more action beyond the screen?

Cross-References

- ▶ Cognitive Psychology Applied to User Experience in Video Games
- ▶ Game Player Modeling

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Design Review Process

- ▶ Technologies for the Design Review Process

Destiny and Destiny 2, an Analysis of an FPS

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Synonyms

Multiplayer first-person shooter; Video Games

Definitions

First-person shooter (FPS)= a genre of games where the camera focuses on a gun (or other weapon) where the objective is to eliminate specific targets.

Multiplayer First-Person Shooter (FPS)

Destiny is a multiplayer first-person shooter franchise developed by Bungie. *Destiny 1* was published by Activision, while *Destiny 2* was self-published by Bungie. *Destiny 1* was released for the Xbox 360, Xbox One, Playstation 3, and

Playstation 4 in 2014. *Destiny 2* was released for the Xbox One, Playstation 4, and Windows in 2017 while getting a Stadia release in 2019. The most recent expansion, Beyond Light came out in November 2020. All games are rated Teen.

Destiny's target audience is anyone who enjoys a science-fiction first-person shooter. The gameplay and mechanics are similar to other popular first-person shooters but with a little hint of difference when it comes to abilities. *Destiny 2* is similar to other first-person shooters, such as the *Halo* and *Call of Duty* games. It has the same basic controls, but the right bumper provides an extra method of attacking, usually a melee option.

The *Destiny* universe takes place in the Milky Way, several thousands of years after the present day. The bulk of the game takes place in a giant open world where the player travels from planet to planet trying to find the Vanguard, high ranking members of the same race as the player character, to rally together in hopes of reclaiming their home from the alien race known as the Cable, who are led by the warlord named Ghaul. In the beginning of the first game, they come to Earth and try to steal the Traveler's Light, who is a moon-sized god that granted the power of the light to humanity and its allies.

In terms of the HUD, there is a health bar on the top middle that only appears after the player takes damage. The bottom left lists of the player's ammo, grenade, melee ability, and super energy bar. The top left houses a radar (when available). Players can compete in several player versus enemy modes to earn loot. Loot ranges from common, uncommon, rare, legendary, and exotic. They all drop from enemies corpses form of an engram, which is a dodecahedron that is colored to show rarity. From the most common to rare the colors are white, green, blue, purple, gold/yellow. There are a few other ways to get rare loot, which include getting them from stories, bounties, quests, doing a raid which is the hardest player versus enemy quest players can do, or doing multiplayer. Engrams hold weapons or armor that players can use to upgrade their light level. Light level is a character's armor and weapon rating; basically how much damage they can take and deal to enemies. The player base spends a lot of time collecting armor and weapons; many hope to achieve to collect a full armory.

If there is a point of contention in *Destiny*, it would be their multiplayer matchmaking, called the Crucible in *Destiny 2*. In the first game, players could pick a game mode, but not a map. In *Destiny 2*, the player is unable to pick a game mode or map to play on. This leaves players who wish to only play one mode a bit out of luck; they have to hunt for a custom game and hope that they find a lobby that fits them if they do not already have a group of like-minded players.

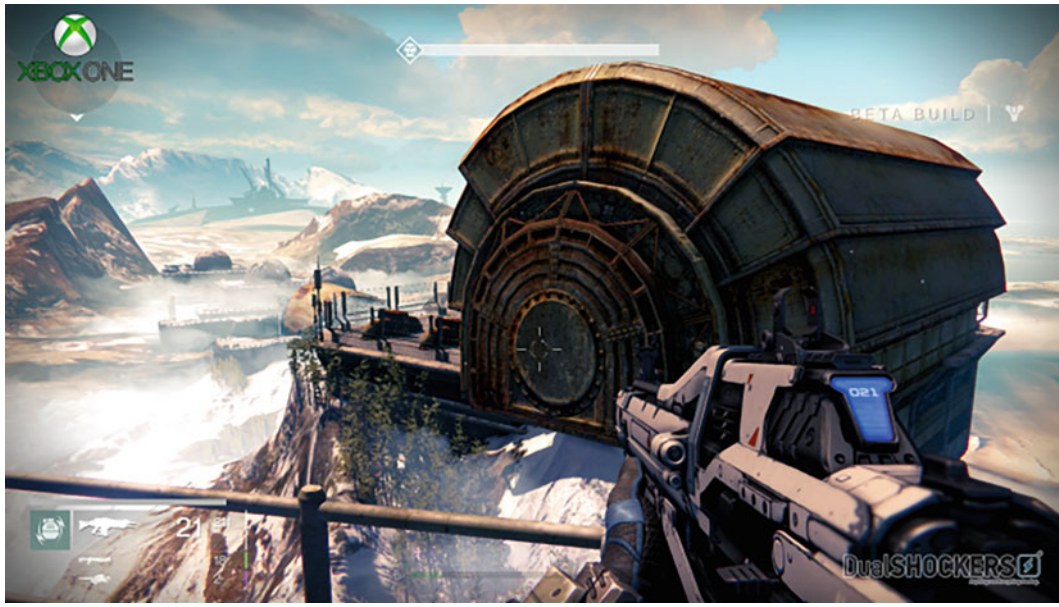
There is also one major controversy with the series: the DLC content and the game itself. In the first game, Bungie did not release the whole game right way. Instead they decided to slowly release it through DLC release. It was not until their final DLC that the game's mechanics were fully realized.

Some players believe that Destiny 2 is an improvement from the original Destiny, but some others opine that the original game is superior (Heather 2021 & Stevryu et al. 2017). To compare and contrast the two versions, we can examine the following:

1. Player Base: Although Destiny is very popular, Destiny 2 has a much larger player base with over 20 million players.
2. Weapons: Players can carry three weapons in both Destiny and Destiny 2. The major advantage of Destiny 2 is that all weapons are already fully leveled up, unlike Destiny where players have to spend time and resources to level up a weapon. Destiny 2 also provides more exotic weapons categorized into kinetic, energy, and power weaponry.
3. Story: Unlike the original Destiny, every story and plotline in Destiny 2 has a clear beginning, middle, and end.
4. Character Development: Both Destiny and Destiny 2 offer three character classes, namely, Titan, Hunter, and Warlock. In Destiny, players can customize the subclasses. In Destiny 2, customization is replaced by new special abilities for each character.
5. Armor: Destiny 2 allows customization of armor with mods and perks.
6. Content: Compared to the original Destiny, Destiny 2 has more worlds to explore, more

raids and dungeons, and more competitive modes like Gambit and Crucible.
7. Hybrid PvP/PvE: Destiny 2 offers a hybrid PvP/PvE mode that does not exist in the original Destiny.
8. Raids: Both Destiny and Destiny 2 require a team of six players to complete a raid mission. Destiny 2 provides additional Guided Games feature for solo players to team up with others to complete missions.

In conclusion, Destiny 2 is certainly an improvement over the original Destiny. Nevertheless, every player is entitled to his or her own



Destiny and Destiny 2, an Analysis of an FPS, Destiny 1 Destiny 1

Destiny and Destiny 2, an Analysis of an FPS, Destiny 2 Destiny 2

opinion as far as what game he or she likes the most.

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Detecting and Preventing Online Game Bots in MMORPGs

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Synonyms

Cheating; Detection; Game bot; MMORPG

Definition

Game users cheat to level up and accumulate cyber assets in an easy and fast manner without sufficient effort. One of the most widely used tools for cheating in online games is the game bot, which enables users to cheat in a convenient way by automatically performing the required actions. Therefore, game companies employ various security solutions for the detection and prevention of game bots.

Introduction

Online gaming is one of the successful Internet services. In the past few years, online games have become popular and have been generating huge profits. Online game companies generate profits by charging users a subscription fee and selling virtual items to them. Among the various types of games, MMORPGs (Massively Multiplayer Online Role Playing Games) make up one of the most popular genres.

As online games gain economic and social importance, various forms of threats emerge. A variety of methods have developed to parasitize and gain unfair advantages in online games. In this chapter, we focus on cheating actions using the game bot, which is one of the most prevailing reasons why users get banned from the game company.

Game users cheat to level up and accumulate cyber assets in an easy and fast way without sufficient effort. Game items and game money are critical to increasing the survivability of in-game characters by improving their power and reputation. In particularly, MMOPRGs are designed such that players take prescheduled courses to achieve high-level characters and become rich in cyber assets. These courses require the users to spend a considerable amount of time on repetitive play.

To skip these time-consuming processes for achieving high-level characters and acquire more cyber assets within a short period of time, users begin to cheat. One of the most frequently used tools for cheating in online games is the game bot. The game bot enables users to cheat in a convenient way by automatically performing the required actions. A typical game bot is an auto program that plays the game instead of a human.

Some users are eager to achieve a high level within a short period of time, so they buy virtual goods or higher-level accounts by paying real money. Game items and currency gained through game play can be sold and monetized into real currency. Real money trading of virtual goods is also one of reasons why players cheat. The illegitimate activity of gathering virtual goods in online games primarily for real money is called gold farming (Davis 2009). Gold farming is one of the most problematic issues in online games because gold farming is not only performed at an individual level but also by a factory-sized illegal group. “Gold farming groups” are industrialized organizations that gather and distribute virtual goods for capital gain in the online gaming world (Keegan et al. 2010). Real money trade by

gold farming groups has now become a social problem in many countries. Real money trade leads to tax evasion, illegal labor in developing countries, and damage to the game company. Gold farmers mainly use game bots for a large-scale operation, thus saving on labor costs.

Cheating in online games is no longer a personal problem of a player and causes damage to other players since online games maintain a massive set of players who form social relationships with other players.

Cheating causes an unfair competition, spoils other players' fun, and makes other players lose their motivation for the play. For example, bot users play the game much longer without a break, while playing continuously for a long time is difficult for human players. Since the activities and extraordinary abilities of game bots are noticeable to other players in the game world, they can make users feel that the game is unfair and cause users to leave the game. For companies, the detection and prevention of cheating incur a significant expenditure. When players use a game bot, they can reach the highest level in a shorter period of time than that expected by the game designers. Then, the users at the highest level have no more game contents to enjoy and leave the game. Consequentially, cheating causes various losses to the game company. It reduces the item sales amount, and eventually the number of players, and shortens the game lifecycle.

Online game companies realize the seriousness of the damage caused by a gold farmer group; they detect game bots and then ban their accounts or IPs to neutralize the gold farming group. They actively hire monitoring personnel, called GM (Game Masters), and deploy security solutions on both the client side and the network side. In addition, they adopt log analysis systems to detect game bot users.

Here, we will discuss some literature on state-of-the-art game bot detection and prevention methods, with the aim to fully understand the current prevention techniques and to advance countermeasures against the use of game bots in online games.

Literature Review

Technology Trends

Game bot detection methods have evolved over the years in the following order:

- Client-side detection and network side detection (first generation)
- Server-side detection (second generation)
- Surgical strike (third generation)
- Proactive detection (advanced surgical strike)

The first-generation methods are signature-based methods. Client-side bot detection including antivirus programs and CAPTCHA (Completely Automated Public Turing test to tell Computers and Humans Apart) is a first-generation method. The first generation of commercial products could be detoured with reverse engineering. In addition, CAPTCHA can annoy users.

The second generation is the server-side detection. This method mainly focuses on distinguishing between a bot player and a normal player by analyzing server-side log files. As gold farming becomes industrialized, the detection of all bot users is difficult to implement because of the huge number of bot users. It is not efficient because gold farming groups provide standby characters against being banned by the game company. Against the endless arm race battle between gold farming groups and game companies, we need a more efficient and selective detection method. The third-generation method is a surgical strike policy (Woo et al. 2011, 2013a, b). This method examines a gold farming group's ecosystem and performs banning to maximize the banning effect while minimizing the banning operation.

The current approaches in previous research rely only on the analysis of behavior patterns. When the players' activity patterns are distinguishable from the majority, these players are suspected to be malicious users. Most game companies take an action that bans bot users' accounts when they repetitively use a game bot.

Previous detection methods are reactive; they detect bot users only after users have repetitively exhibited malicious behavior. For a proactive and preventative response against malicious users, the social network analysis-based detection methods including the study on the contagion over the social network are used.

Client-Side Bot Detection Methods

Client-side methods are focused on signature-based, client-side BOT detection, such as anti-virus programs and CAPTCHA. PunkBuster (http://www.punkbuster.com) was the first attempt to avoid cheating on the client side. This tool monitors a client machine looking for any abnormality and sends a screenshot of the client to the game server. Khanh (2010) proposed a specifically designed module called GameGuard, which is added to the client to guard against possible cheating attempts from game players. GameGuard hides security-related modules so that hacking tools cannot see them, by using certain system techniques to interfere with some operations of Windows systems. It also places hooks in the Windows kernel mode to examine new processes entering the system and check whether these processes are hacking attempts or not.

CAPTCHA requests the answers that can be easily solved by humans but are difficult for bots to solve. Yampolskiy and Govindaraju (2008) proposed the integrated testing procedure as part of the game step performed by the player during the game in order to distinguish bots from legitimate human players. Golle and Ducheneaut (2005) demonstrated the CAPTCHA test embedding in the game world in order to minimize the disruption compared to the out-of-band use of CAPTCHAs.

However, the first generation of commercial products could be detoured with reverse engineering. In addition, the client-side solution has other drawbacks. Client-side solutions run on the client computer. This causes a load on the client computer and can cause any inconvenience to users. CAPTCHA can annoy users when they receive questions while they are playing.

Network-Side Detection Methods

Network-side detection methods are designed to look into network traffic or network packets generated by the client when the client communicates with the game server. This type of method detects network traffic burstiness and anomalies in the command timing, response time, and traffic interval. Some methods are designed to detect different reactions of humans and game bots to changes in network conditions such as protocol changes or the occurrence of traffic lags.

When a company changes its network protocol, game bots lose their connection and pause to update their programs so that they can be fitted to the changed protocol. When a company generates a traffic lag by design, human players react to the change sensitively, for example, by continuously clicking their mouse or keyboard buttons until the connection resumes, whereas game bots are not sensitive.

The network-side solution to a nonclient bot is to ask a question to the user who can give a right answer when she uses the client software provided by the game company. The nonclient bot does not operate on the client software, so it cannot provide the right responses for specialized questions.

Similarly, most network-side solutions mainly adopt a method that frequently changes the network protocol or applies cryptography to encrypt/decrypt network transmission.

For the P2P game, the game company facilitates a method for participants to reach a consensus on the current state of the game in a way that prevents malicious individuals and groups from cheating. Securing the protocol that delivers messages when peers communicate is a solution to this security issue.

The NEO (GauthierDickey et al. 2004) protocol is designed to prevent protocol-level cheating in P2P games. This protocol enables to accomplish the exchange of update information among players in an authenticated manner. It verifies the identity of the sender and registers updates in advance to ensure that every party has chosen its update for a round before it may read the updates of the other players. It also attempts to ensure game state consistency by confirming which

updates have been received by which peers. The details of the NEO protocol (Hu and Liao 2004) are as follows: It divides the time into uniform intervals, called rounds, in which each player sends an update to all the other players. Each update is encrypted, and in the following round, the players send the corresponding key to each other.

Corman et al. (2006) invented a more secure protocol called SEA (Secure Event Agreement). The authors investigated the drawback of the NEO protocol and then proposed an improved version of this protocol. They focused on the protocol for communications rendering information such as the position, direction, and action of virtual entities. The SEA protocol signs an entire event message and binds the message to a particular round and group.

Most of the network-side countermeasures are based on a cryptographic methodology to guarantee network traffic integrity and confidentiality. To secure network traffic, it is necessary to encrypt and decrypt the packets. However, this requires a considerable amount of computing power, and the error in this process can spread to all concurrent user connections. This can cause single-point-of-failures, so game companies are reluctant to adopt strong network-side cryptographic methods.

Server-Side Detection Methods

Server-side methods use the log collected in the server of the company. The company records user behaviors as a log in the database. Game bots display repeated and biased patterns in their actions differing from human players. Technically, server-side methods adopt data mining-based or statistics-based methods. First, these types of methods extract the feature set from the log. Then, classification using the feature set is performed; classifiers are automatically built through learning from data by using data mining or statistical methods.

Feature extraction is a critical component of behavior-based detection techniques. First, we build a taxonomy of behavior-based features that classifies previous research in a systematic way. Then, we review previous works based on this taxonomy.

User behaviors in the gaming world include major activities such as move and play. Other socializing behaviors are also a good source for game bot detection. MMOPRGs are designed to make people interact with others in order to complete difficult tasks and then level up their characters and have fun playing the game through such interactions. User behaviors can be categorized into sole behaviors and social behaviors. The main sole behaviors are movement and play. In MMORPGs, a play encompasses combat, harvest, and healing. Social behaviors mainly include party play, communication, trade, and community activity.

- Party play means that two or more players form a group to undertake quests or missions together. Users in party play typically share experience points, money, and items acquired upon completion of successful quests. Most MMORPGs are designed to require party play.
- Players in the game communicate with other players by sending text messages or e-mails. In the gaming world, players can trade items. In general, players exchange items with other items of equivalent value or money. Trade patterns provide a good clue to detect abnormalities, particularly gold farming groups.
- In general, players maintain a friend list for easy co-play and communication. Player A sends a friend request to player B. When player B accepts the request from player A, they become friends. They show up in the friend list of the other party.
- Players organize a guild to socialize or achieve a similar long-term goal.

Previous works focused on movement patterns and sole play patterns because they used simulation data obtained by operating game bots. This is an alternative method used when a real game log is not available. Bots are programmed, so their movement and play patterns are repetitive and regular. Bot detection models have been proposed based on this fact. Social behaviors have recently been adopted in research. Social

behaviors cannot be obtained in the absence of the cooperation of a game company. Fortunately, several studies provide the analysis results of large-scale real data under the cooperation with game companies.

Now, we will review key papers in detail.

Movement-based methods use the fact that most bots have preconfigured moving behaviors while humans have random moving patterns (Kesteren et al. 2009; Mitterhofer et al. 2009).

- The longest common path (LCP) is a good indicator that measures the regularity in movement patterns. Bots take same paths repetitively, so they have high LCP, while human players show random behavior and thus have low LCP. Furthermore, bot users can turn the bot program on and off, which results in a high variation in regularity. Human players will have low regularity and a low variation in regularity.

Play patterns are widely used for distinguishing between a bot behavior and a human behavior.

- Chung et al. (2013) considered all types of behaviors that can be observed in the game world. They categorized play patterns into Battle, Collect, and Move; specified battle behaviors as Hunting, Attack, Hit, Defense, Avoidance, and Recovery; and built a feature set by using such specified behaviors. The features can be directly retrieved from the game log. Further, they developed the feature set from raw features in order to represent how efficiently a user plays the game. The developed features include combat ability, collecting pattern, and movement pattern.
- Christensen et al. (2013) examined the race duration from both the client side and the server side, and the gap between the duration measured on both sides. They suspected a very short duration time, long duration, and inconsistent duration time between the client side and the server side.
- Platzer et al. (2011) analyzed the sequence of play patterns and identified the differences in the sequences of bots and human players. Since bots can make restricted choices when they play the game, they show limited and repetitive behaviors. The authors implemented their proposed detection tool on a server-side and client-side instance and an in-game client-side add-on that is capable of monitoring its own event horizon.
- Lee et al. (2014) proposed a measure that expresses the extent to which a player behaves repetitively. They analyzed the full action sequence of users on a big data analysis platform. The differences between the action sequences of normal users and bot users were determined.

With respect to social behaviors, party play, communication, and trade have been explored to identify the differences between game bots and human players.

- Kang et al. (2013) focused on party play, which is a group play with several characters, for game bot detection. They pointed out that the game bot forms a party play with a limited number of players, usually other game bots, and has limited actions biased towards collecting game money in the party play.
- Kang et al. (2012) proposed a chatting-based bot detection model. They retrieved chatting contents and derived features by using text mining techniques from the chatting contents. They also derived entropy-based features, chatting-pattern based features, and text features. The proposed detection model assumes that game bots communicate with other bots through limited messages that humans find difficult to understand.

To detect factory-sized illegal groups that operate numerous game bots, i.e., gold farming groups, an understanding of the ecosystem of a gold farming group with respect to the trade patterns is required. The followings are some surgical strike approaches.

- Woo et al. (2011) and Kwon et al. (2015), respectively, identified the ecosystem of gold

farming groups, as shown in the following figure. Gold farmers repeatedly hunt monsters and harvest craft materials to earn game money and to save time. The collected items and game money are delivered to the merchant characters; merchant characters then sell these items for game money. The game money from gold farmers and the acquired money by the item trade through merchant characters transfer to banking characters. Banking characters possess most of the game money in the GFG to sell the game money efficiently.

- Ahmad et al. (2011) considered player characteristics and items and detected contraband networks in terms of players and items. They analyzed clandestine social networks of deviant players in MMOGs (Massively Multiplayer Online Games) along with a network of contraband items sold by these players.
- Oh et al. (2013) utilized the fact that game bots and human players form social networks in contrasting ways. They constructed a social network on the basis of mentoring relationships. They derived features from the play and the trade and added social network-based features. These authors proposed new features based on eigenvector centrality to capture the social influence.
- Keegan et al. (2010) and Ahmad et al. (2011) studied the clandestine trade and trust networks of gold farmers, respectively, and described how gold farmers try to obfuscate their interaction patterns in these networks to evade detection.
- Keegan et al. (2011) discussed the usefulness of studying clandestine networks in the virtual world and their applications to studying their counterparts in the offline world.
- Blackburn et al. (2014) introduced an interesting platform, the Steam Community, an online social network built on top of the world's dominant digital game delivery platform. They performed a thorough social network analysis on the players' social relationships and interactions. They found that the cheaters' network position is largely indistinguishable from that of fair players.

More advanced methods are based on the contagion process in the players' social networks. This generation method is in an early stage.

- Woo et al. (2013a, b) and Blackburn et al. (2014) showed that a social contagion of game bot usage can develop. The first and the third study showed that contagion between players in a social network exists. The second study proposed a modeling method to track the contagion process. This modeling method is based on an epidemic model. Modeling of the diffusion process enables one to predict the future diffusion process and to estimate the likelihood of an individual's bot adoption.
- Ahmad et al. (2013) proposed label propagation to detect gold farmers. The proposed model initially sets the label that indicates the gold farmers, and then, propagates these labels over highly connected networks, such as the mentoring network, housing-trust network, and trade network. To reduce false positives in which normal users are misjudged as bot users, the authors also considered user similarity.

The game company adopts a negative policy for bot users since banning accounts often causes a legal issue between the user and the game company. If the game company selectively targets users for banning, it can ban users for minimizing the compliance risk and maximizing the banning effect at the same time. Identifying influentials in the diffusion process of game bot usage will solve this issue.

- Ki et al. (2014) provided the analysis results on a contagion of game bot usage and identified the influentials in the contagion process. Identifying the influentials in the diffusion of malicious behaviors and understanding the diffusion process of the malicious behaviors is particularly important, as it will give the game company a new opportunity to act proactively and preventively against malicious users.

Conclusions

This survey summarized how the game bot detection methods have evolved in the recent years. It further developed a taxonomy according to the data source for countermeasures and introduced the state-of-the-art literature on the game bot detection and prevention methods. The game bot detection methods have been developed from client-side detection and network-side detection methods to server-side detection methods. Client-side security solutions that are required to be installed on the client computer often cause collisions in the operating system, resulting in user inconvenience. Network-side detection methods such as network traffic monitoring or network protocol changes cause a network overload and lags in the game play, a significant annoyance in the online gaming experience. Server-side methods that are mainly based on log mining of user behaviors produce highly accurate rate and effective rules to detect game bots and do not interfere with the game play. With the evolution of game bot usage, from being used by individual users to gold farming groups, server-side methods have been advanced to detect gold farming groups. Further, the detection methods have become more proactive, getting hints from the contagion process of the game bot usage on a social network that can be observed in online games.

Through this survey, several research gaps have been identified.

First, the surgical strike methods for the detection of gold farming groups have not been explored sufficiently thus far. As gold farming increases, efficient and effective detection methods are needed and the current literature has much room for improvement.

Second, the server-side methods mostly focus on feature extraction and apply existing machine learning algorithms to build automatic classifiers. However, an algorithm specialized for game bot detection has not been developed thus far. An algorithm that reflects the characteristics of game bot users or gold farming groups may be more effective than the existing algorithms.

Third, game bots are evolved to avoid detection, so behavior-based methods become outdated in a short span of time. More features that reflect the cheater's psychology and the behavior lifecycle can be used for generating more genetic models. In addition, behavior features are generally game-specific, so generic features also should be considered.

This survey will hopefully boost researchers' interests in this area of study, help in determining the research agenda, and finally, lead to the development of countermeasures against game bots.

Cross-References

▶ Secure Gaming: Cheat-resistant Protocols and Game History Validation

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Detection

▶ Detecting and Preventing Online Game Bots in MMORPGs

Diagram

▶ Unified Modeling Language (UML) for Sight Loss

Dichromate Gelatin (DCG)

▶ Holography as an Architectural Decoration

Diegetic Interfaces

▶ Game Interface: Influence of Diegese Theory on the User Experience

Diffraction Microscopy

▶ Holography, History of

Diffusion-Reaction Problems

▶ Lattice Boltzmann Method for Diffusion-Reaction Problems

Digital Collectibles

▶ NFT Games

Digital Communication

▶ Life-Size Telepresence and Technologies

Digital Games

▶ Computer Games and the Evolution of Digital Rights

Digital Games for Animals

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Definitions

Digital games aimed at animal players are a growing area in both entertainment and research, enabled particularly by the mass availability of touchscreen technology. These games rely on animals' natural proclivity for play and can facilitate playful interactions between species.

Prerequisites for Digital Play in Animals

Humans are far from the only species known to engage in playful behavior. Wirman et al. (2011) argue that "all mammals play, including humans," and play-like behaviors have also been identified in birds, reptiles, fish, and invertebrates such as octopuses (Burghardt 2005). While the evolutionary dynamics and psychological mechanisms of play are not yet fully understood, it is known that in both humans and other animals, playing is a crucial prerequisite for physiological, psychological, and social development (Bekoff 1972) and play deprivation can result in serious developmental deficiencies in adulthood (Hol et al. 1999). Based on this evidence, scholars such as Sutton-Smith (1997: 218) have advocated for a definition of play which encompasses both humans and animals.

Animals are also known to interact with technology in a variety of ways. Many pet owners have observed their animal companions watch television, and animals' engagement with screen media can be meaningful. Research suggests, for example, that dogs can recognize other dogs on the screen and distinguish them from other species using visual cues alone (Autier-Dérian et al. 2013).

Service animals are often trained to use technology. One example is "canine augmentation technology," developed to foster more efficient dog–human communication in search and rescue operations (Ferworn et al. 2006). Digital technology also plays a major role in animal cognition research, with great apes such as the male bonobo Kanzi being trained to use a touchscreen interface to communicate with humans in a lexigram-based language (Greenfield et al. 2008). More recently, underwater acoustic touchscreens have been developed to facilitate human–dolphin communication (Herzing 2016).

Digital games for animals use technology as a vehicle for animals' natural playfulness.

Examples

Whereas some digital games for animals are commercial products targeting pet owners, others are

developed for research purposes or for use in specialized facilities such as animal rehabilitation centers and zoos. Of the former variety, most games appear to target cats and feature a similar mechanic: tracking and tapping an object moving on the touchscreen. *Friskies Jitterbug* and *Cat Alone* are the better known of many such titles. A number of similar games, such as *Jolly Dog*, also exist for dogs.

Research-based games and games used in specialized settings often focus on enriching the lives of captive animals, targeting species as diverse as parrots (Woodman 2014), penguins (Westerlaken 2017), and orangutans (Webber et al. 2017). Many such games promote cross-species play. One example is *Pig Chase*, an experimental game developed in the Netherlands, which involves farm pigs interacting with a large touchscreen installed in their pen. The objective is for a pig to use its snout to touch a moving ball, which is remotely controlled by a human player. When touched, the ball fires off colorful sparks. The game keeps track of each pig's individual performance and has a leaderboard which can be viewed by the human on their tablet. The aim of the project is to relieve the pigs' boredom, which is a major issue in intensive farming, as well as facilitate cross-species play and, through it, reduce "the distance between farming practices and the general public" (Meijer 2016: 71). Other examples of cross-species digital play have involved orangutans (Wirman et al. 2011; Webber et al. 2017), cats (Westerlaken and Gualeni 2014), dogs (Wingrave et al. 2010), and hamsters (Cheok et al. 2011).

Rationale

One of the main reasons to explore digitally mediated play in animals is its potential to improve their lives. Digital games can provide cognitive stimulation and enrichment to captive animals, mitigating the issue of boredom and facilitating cognitive development (Baskin and Zamansky 2015). Experimental evidence suggests playing digital games can relieve stress and depression in home alone dogs (Geurtsen 2014). Another issue digital play can address is animals' sedentary lifestyle (Pons et al. 2014). One example is *Feline Fun Park*, a game for cats which has an automatic mode where the level of challenge is adjusted based on the animal's activity level (Young et al. 2007).

Digital play can also benefit human–animal interactions. Some digital games, such as *Canine Amusement and Training*, are designed to facilitate dog training (Wingrave et al. 2010). Other digital games, such as the human–orangutan collaborative game deployed at Melbourne Zoo, aim to increase visitors' empathy for animals while providing the latter with environmental enrichment (Webber et al. 2017). Another project, *Apps for Apes*, included an iPad donation campaign for captive orangutans as a way of raising public awareness about orangutan survival in the wild (Smith 2011).

As an area of research, digital play in animals can be regarded as part of the wider domain of animal–computer interaction (Baskin and Zamansky 2015) whose aims and concerns it shares. These include improving animals' life expectancy and quality, assisting working animals in their legal functions, deepening our understanding of animal cognition, and fostering better communication between species (Mancini 2011). Studying animals' digital play may also help us better understand the psychology and the roles of play – including in our own species (Wirman 2013).

Challenges

Despite their potential, digital games for animals present a number of challenges and concerns, most notably of an ethical nature. Play is meant to be a voluntary and autotelic (intrinsically motivating) activity (Denzin 1975), yet this is not always the case with digital games for animals, which in many settings are reward-based (Wirman et al. 2011). It is thus often unclear whether the animal is genuinely playing or exhibiting trained

behavior (Baskin and Zamansky 2015). Some breeds of dogs display strong predatory patterns when engaging with digital games, suggesting the animals may be trying to hunt, with the failure to capture the prey resulting in frustration (Baskin et al. 2015).

Another concern is the short- and long-term physiological and behavioral effects of digital play in animals (Westerlaken and Gualeni 2014). As many other aspects of animals' technology use, these require further research.

A more technical challenge lies in the fact that modern technology is overwhelmingly designed for human use and is not easily accessible to other animals. Most mammals, for example, have dichromatic color vision, as opposed to the trichromatic vision in humans (Neitz et al. 1989), meaning that they are able to distinguish between a more limited range of colors. Avians such as parrots can recognize images on a flat-panel display but not a cathode-ray-tube screen, due to the latter's flickering (Woodman 2014). Many animals, including dogs and cats, also have a different field of vision and depth perception compared to humans (Pons et al. 2017), making standard tablet screens suboptimal for their use. Additionally, most touchscreens are neither durable enough nor responsive to claws, rendering standard tablets nearly unsuitable for cat and dog use (McGrath 2015), despite the proliferation of "feline" and "canine" games on these devices. Thus a crucial challenge when designing a digital game aiming at animals is to ensure it uses "species appropriate" (McGrath 2009) technology and undergoes sufficient user testing with actual animals to mitigate the developers' inevitable anthropocentrism (Westerlaken and Gualeni 2014).

Cross-References

- ▶ Cognitive Psychology Applied to User Experience in Video Games
- ▶ Cybersickness
- ▶ Psychological Game Design

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Digital Geometry Processing

▶ Modeling and Mesh Processing for Games

Digital Humans

▶ 3D Avatars in Virtual Reality Experience

Digital Image

▶ Rendering Equation

Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces

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Synonyms

Face detection; Face recognition; Haar cascade classifier; Image processing; Occluded faces

Definition

Detection of partially occluded faces in digital images using AdaBoost Haar cascade classifier is a viable technique of face detection if the cascade training procedure is modified.

Introduction

Face detection is one of the more popular applications of object detection in computer vision. The computer uses a series of mathematical algorithms, pattern recognition, and image processing to identify faces from an image or video input. Over the years, the technology of detecting faces has evolved proportional to its usage in various applications. The most known algorithm for face detection was introduced by Viola and Jones in 2001. They proposed a framework that produces real-time face detection by the means of a novel image representation known as integral image and incorporated the Haar basis functions that was used in the general framework of object detection (Papageorgiou et al. 1998) with AdaBoost and implemented it in a cascade structure, creating a boosted cascade of weak Haar-like feature classifiers (Viola and Jones 2001).

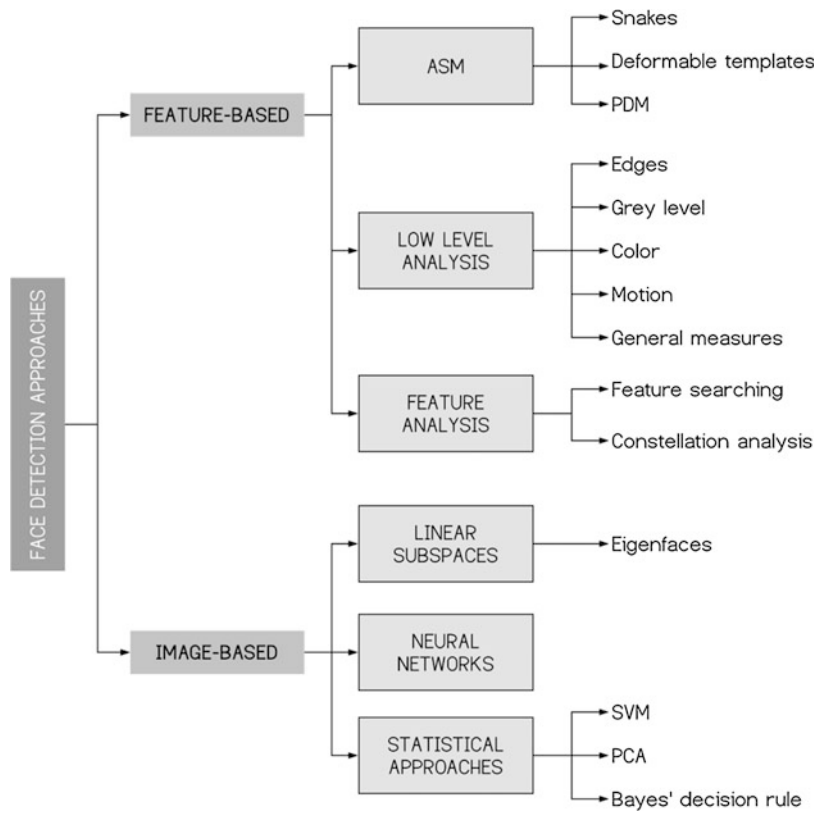
Since the introduction of the Viola-Jones framework, various researchers have adapted the framework and made improvements to the original framework keeping with the advancements of technology. The most recent application of the framework was via GPU architecture and combining Viola-Jones' method with a neural network. The contribution of Viola and Jones is only surpassed by Lienhart and Maydt in 2002 when they extended the set of Haar-like features used in the framework. Their contribution of rotating the Haar-like feature by 45° and also a center-surround feature provided the cascade with more features to compute without increasing the computation time (Lienhart and Maydt 2002).

State-of-the-Art Work

Classification of Face Detection Techniques

Face detection approaches can be grouped into two distinct approaches: feature based and image based. Feature-based approaches in face detection requires the extraction of facial features from an image and comparing it with a knowledge base of face features, whereas image-based approaches attempts to get the best match while comparing training images against testing images (Modi and Macwan 2014). Figure 1 illustrates the classification of face detection algorithms.

The feature-based approaches consist of active shape models (ASMs), low-level analysis, and feature analysis. Active shape models were developed by Tim Cootes and Chris Taylor in 1995, where a shape of an object in the form of a statistical model is used to find the object in a new image by the means of iterative deformation to fit the new object (Cootes et al. 2000). Low-level analysis is a feature-based approach that uses visual features such as edges, gray scale levels, color information, motion, and general measures to differentiate facial features of a face with its surroundings in an image (Singh et al. 2017). Meanwhile, feature analysis refers to the usage of the geometrical facial features to locate faces irrespective of illumination, pose, and angles. There are two methods of implementing feature analysis in face detection, which are feature searching, such as Viola-Jones method and constellation method.



Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces, Fig. 1 Classification of face detection algorithms

Meanwhile, image-based approaches aim to improve the unpredictability of the various feature-based approaches. The strategy this approach utilizes is treating face detection as a pattern recognition problem, whereby the specific application of face knowledge is steered clear from and the issue is tackled as learning to recognize face patterns from examples (Hjelmås and Low 2001). The fundamental approach of image-based methods relies on training procedures that classify the samples as face and non-face classes. The straightforward approach is illustrated by template matching. Most of the methods rely on an exhaustive search done by a window scanning algorithm in an attempt to detect faces. However, there are various methods under the image-based approach such as linear subspace methods, neural networks, and statistical approaches that are able to accomplish the task of face detection successfully.

Since this entry aims to improve face detection of partially occluded faces using the Viola-Jones method, there are some modifications that have been done on the original algorithm that are worth mentioning. In 2002, the Viola-Jones method was enhanced by using an extended set of Haar-like features which rotates the Haar-like features by 45° that improved the false positive rates (Lienhart and Maydt 2002). The initial Viola-Jones method has gone through various enhancements and modification. Later, a new variant of AdaBoost known as asymmetric AdaBoost was introduced (Viola and Jones 2002). Then another form of boosting was introduced when FloatBoost was used in a detector-pyramid architecture to detect and recognize faces (Zhang et al. 2002). In 2003, researchers introduced a boosting chain to enhance the cascade model for object detection which was later used for face detection (Xiao et al. 2003). A novel variant of Viola-Jones that uses a nested cascade structure for multi-view face detection proved to be successful for detection of faces from various viewpoints (Huang et al. 2004). In 2005, a similar approach as Viola-

Jones was introduced. However, it used joint Haar-like features for classifiers (Mita et al. 2005). It became increasingly important to detect faces that are non-frontal or multi-view faces in images and video. A research put forth the idea of using width-first search (WFS) tree structure to improve the performance of speed and accuracy of the detection by implementing a vector boosting algorithm based on the real AdaBoost algorithm, and a piecewise function with LUT was used to aid with the weak classifiers (Huang et al. 2005).

Other hybridization of the Viola-Jones method includes using color information whereby skin detection is used by computing the skin percentage (Mahmoud et al. 2011). Another popular variation is to combine the Viola-Jones method with a neural network, where the neural network is used to classify faces with non-faces processing stage (Da'san et al. 2015). Additionally, the Viola-Jones method can be integrated with other known methods such as shape constraints (Cristinacce and Cootes 2003), low-level saliency (Cerf et al. 2008), and with corner points using Shi-Tomasi detector (El Kaddouhi et al. 2017). Recent development of the Viola-Jones detector involves implementation via graphics processing unit (GPU), multi-threaded central processing unit (CPU), and field-programmable gate array (FPGA). The proposed usage of FPGA hardware architecture design with AdaBoost face training and detecting algorithm improved the performance of the face detection algorithm (Lai et al. 2007). In 2011, researchers proposed a technique that uses GPU computing to implement a modified Viola-Jones framework (Devrari and Kumar 2011). Moreover, the study done to compare the implementation of the Viola-Jones framework in a single-threaded CPU, a multi-threaded CPU, and a GPU implementation using CUDA shows the GPU implementation to be the fastest (Krpec and Němec 2012).

Application of Face Detection

Over the years, the popularity of face detection has yet to cease. The usage of face detection in the industry has only increased with the age of technology. Face detection now plays an important role in face recognition and biometric authentication. Additionally, face detection is also extensively used in the software embedded in digital cameras. Most digital cameras and cameras on mobile phones use face detection to detect and focus on the faces to reduce blurriness. Meanwhile, social networks and social applications such as Facebook and Snapchat use face detection to further enhance user experience (Rajawat et al. 2017). These application and usage of face detection further motivates researchers to optimize and address the issues faced in face detection as this directly impacts the industrial application of face detection.

Open Issues in Face Detection

The challenges encountered in the field of face detection and recognition in digital images are commonly expressed as A-PIE, which represents aging, poses, illumination, and expression (Mahalingam et al. 2014). Humans are able to identify faces almost instantaneously despite the changes that occur due to aging; however, computers do not have this ability. The difficulty encountered due to aging is still being regarded as a problem as the physical changes of a person over different periods of time can be subjected to external factors such as injuries and cosmetic surgeries. In terms of poses, the degree of head rotation will affect the amount of facial features available for detection. Illumination also plays a part in the detection of faces. If minimum lighting is available in the image, then it becomes a challenge to differentiate the change in pixel value which is required to detect features of a face. Finally, in terms of emotion, the changes in human expression would not be recognized easily if the face detection model is not trained to recognize a variation of emotion, as the general structure of the face changes when a person experiences different emotions. Additionally, partial occlusion poses a problem in face detection as well. Some of the A-PIE challenges can also be considered as a partial occlusion problem as well.

Researchers began noticing that partial occlusion of faces affects the overall detection rate of the algorithm. Most of the face detection techniques work by searching facial features such as mouth, nose, and a set of eyes in images in a joint search. Therefore, occlusions such as sunglasses and scarves hinder the detection of faces which consequently affects the performance of the detection algorithms.

The detection of faces in images are made difficult with the limited visibility of faces due to various factors such as pose variation, poor lighting, and occlusions due to hats, scarfs, hair, and foreign objects. To accurately detect these partially occluded faces in images without using artificial intelligence (AI) requires an approach that does not sacrifice too much in terms of computation time and false positive and negative rates.

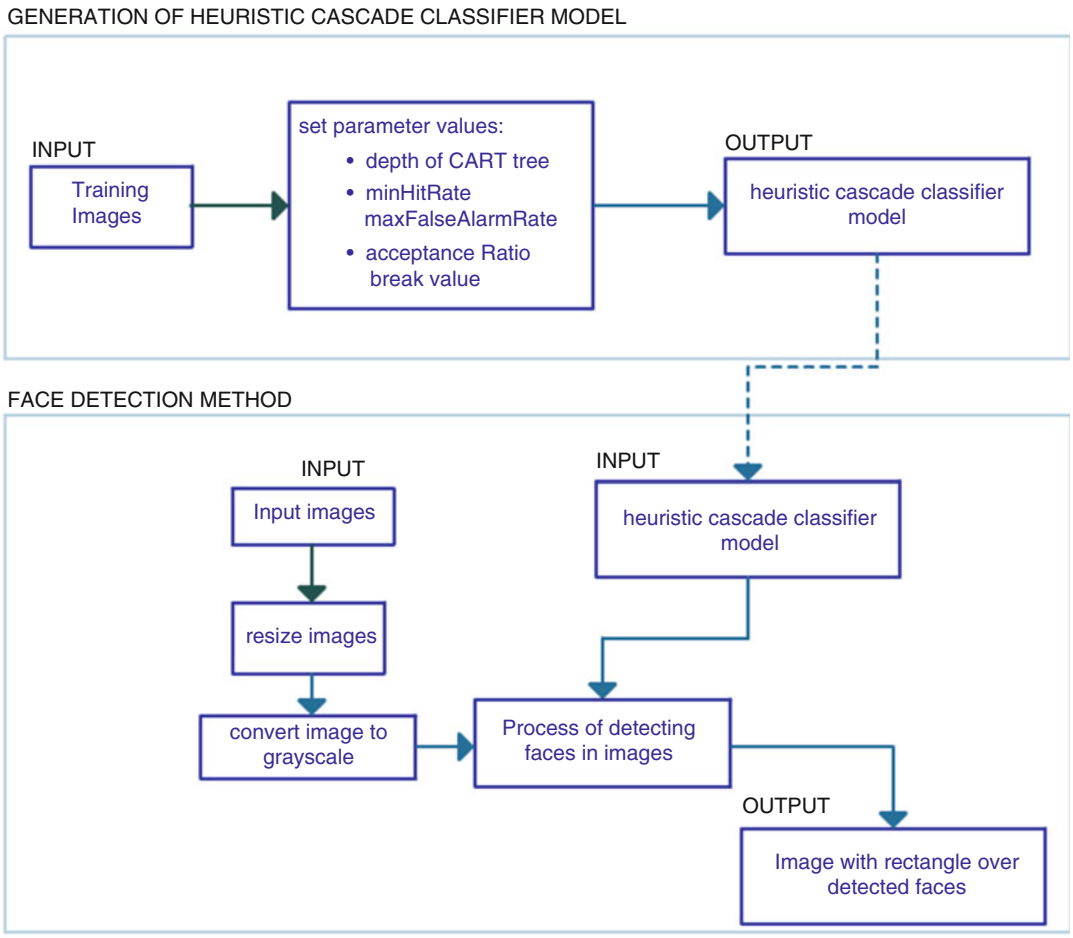
Despite all these problems, the Haar cascade model can be used to improve the detection rates of partially occluded faces with proper calibration. If the model is trained with sufficient images that has a variation of occlusion and A-PIE characteristics, the model will be able to detect faces in said problematic conditions. Additionally, the sensitivity of the Haar cascade classifier model training also influences the rates of detection and false positives that would be given in the face detection.

Heuristic Haar Cascade Classifier Model

A heuristic Haar cascade classifier can be created by setting different training parameters that within the threshold of the Haar cascade classifier model from Lienhart and Maydt. The parameters that influence the detection rates of faces are the depth of the decision tree, minHitRate and maxFalseAlarmRate. These parameters determine the number of features or weak classifiers selected in a particular stage, in addition to the performance of the cascade in terms of detection rates. Moreover, minHitRate and maxFalseAlarmRate also influence the value of the acceptance ratio break value. Once the acceptance ratio break value is achieved, the heuristic cascade model is created; otherwise, a new stage of cascade is added when the maxFalseAlarmRate is reached. The value of the boosting parameters will affect the detection rates of partially occluded faces in images. The integration of optimal tree depth value and boosting parameter values in the cascade training will create a heuristically boosted cascade model. The heuristically boosted cascade classifier model is then used in the architecture of the any feature-based approach of face detection in order to detect partially occluded faces in images.

In order to achieve the best results of face detection, the input image has to go through some preprocessing steps, which are resizing and converting the color space from RGB to grayscale. These two steps are taken to ensure that the best experimental results are obtained for the detection of partially occluded faces in images. Since grayscale images are used to train the cascade, therefore, when executing the face detection algorithm, it is best to use grayscale images. Furthermore, the computation time of a grayscale image is much faster compared to an image that uses three channels. The dimensions of width and height used in the training of the model are usually quite small. Hence, to accommodate this, the input image has to be resized to be twice as small as the original image. Then the trained cascade model is used to detect faces in the image. The detection process involves a subwindow sliding over the preprocessed input image in various scales using the cascade model to evaluate the probability of the sub-window containing a face. In the output, the detected faces or objects in the image have rectangles drawn over them. Figure 2 illustrates the flow of training the heuristic cascade classifier model and the detection of faces in images.

The effectiveness of the heuristic cascade classifier model can be tested using ROC curves, confusion matrix, and comparison tests. The ROC curve is used to analyze the accuracy of the model whereby it can be inferred that the closer the curve is to the top left corner of the graph, the more accurate the cascade model. From the confusion matrix, the F1 score can be calculated. This score is the ratio between accuracy and precision. The Haar cascade classifier models tested for the detection of partially occluded faces needs to have a balanced result between accuracy and precision due to the nature of the



Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces, Fig. 2 Method of Implementation

features available. For the detection of partially occluded faces in images, one of the factors that would influence the efficiency of the classifier model is the depth of the CART tree. The ideal tree depth would ensure that sufficient feature information is preserved in to enable quick detection without underfitting the CART tree. However, having a high value of tree depth would not be ideal in the case of detecting partially occluded faces in images as a lot of facial features would be discarded due to overfitting the tree. Additionally, the detection rates of a CART tree with a low tree depth will end up taking too much time as it would have to loop through more feature information from the tree.

Figure 3 shows the result of three sample images being tested with three different Haar cascade classifier models which are Haar_frontalface_default, Haar_frontal_face_alt, which are classifier models by Lienhart and Maydt, and a heuristic Haar cascade classifier model trained to detect partially occluded faces.

From Fig. 3, it can be observed that the heuristic cascade works better in detecting partially occluded faces where it was able to recognize facial features under less favorable conditions.

Table 1 shows the confusion matrix analysis preformed to test the accuracy and sensitivity of the cascade classifier models.

Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces, Fig. 3 Sample images: (**a**) heuristic Haar cascade classifier model; (**b**) Haar_frontalface_default; (**c**) Haar_frontal_face_alt

Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces, Table 1 Confusion matrix analysis

	Heuristic cascade	Haar_frontalface_default	Haar_frontalface_alt
Accuracy	0.6525	0.5290	0.4843
Recall	0.6945	0.5336	0.5199
Precision	0.8683	0.9839	0.8759
F1 score	0.7717	0.6919	0.6525

The heuristic cascade classifier model is trained with using images that have various levels and types of occlusion. Additionally, the training parameter values are calibrated to enhance the detection of partially occluded faces. The accuracy and true positive rate or recall of the heuristic cascade classifier model is much higher compared to both the other cascade models. However, the precision of Haar_frontalface_default and Haar_frontalface_alt is much better than the heuristic cascade classifier model. Despite this, the ratio of sensitivity and specificity of the heuristic cascade classifier model is 10.9% and 16.7% better compared to the other two cascade classifier models Haar_frontalface_default and Haar_frontalface_alt, respectively. This means that the heuristic cascade classifier model is superior in detecting partially occluded faces when compared to the other two cascade classifier models provided by Lienhart and Maydt.

Additionally, by visually comparing the detection of each cascade model, it is observed that the

heuristic cascade classifier model performs better than the other two classifier models in detecting partially occluded faces in digital images. The heuristic cascade classifier model outperforms the Haar_frontalface_default and Haar_frontal_face_alt classifier models contributed by Lienhart and Maydt by 23.66% and 21.7%, respectively, in detecting partially occluded faces in images.

Conclusion

A heuristically trained Haar cascade classifier model can be used in order to detect partially occluded faces in digital images. By training the Haar cascade classifier model with various levels and types of occlusion, it increases the probability of detecting partially occluded faces in images. During the training phase, several training parameters can be heuristically determined in order to further enhance the detection of partially occluded faces in images.

Cross-References

► Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications

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Digital Preservation

▶ 3D Game Asset Generation of Historical Architecture Through Photogrammetry

Digital Process

▶ Pipeline of 2D Vector Animation in Television Series

Digital Production

▶ Pipeline of 2D Vector Animation in Television Series

Digital Sports

▶ Diversity in Gaming and the Metaverse

Digital Storytelling

▶ Narrative Design

Digitally Encoded Surfaces

▶ Tangible Surface-Based Interactions

Direct Digital Manufacturing

▶ 3D Printing, History of

Direction

▶ Game Development Leadership Tips

Disney Toontown Online, a Massively Multiplayer Online Role-Playing Game

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Synonyms

Action adventure game; MMORPG; Multiplayer game

Definitions

MMORPG = Massive multiplayer online role-playing game is a multiplayer game designed to be played online simultaneously by a large number of players.

Multiplayer game = a game that is designed for multiplayer mode where two or more players are expected throughout the entire gameplay.

Action adventure game = a game that combines core elements from both action game and adventure game genres.

Introduction

Disney Toontown Online was a massively multiplayer online role-playing game (MMORPG) developed by The Walt Disney Company (Madej and Lee 2020). It was first released in 2003 and it allowed players to create their own cartoon avatars called "Toons" and explore a virtual world filled with various activities, quests, and challenges.

In Toontown Online, players could battle against comical villains called the "Cogs" who were trying to take over the world of Toontown. Players could team up with other Toons to defeat the Cogs using a variety of gag weapons such as cream pies, squirt guns, and anvils.

Toontown Online was popular among both children and adults due to its colorful graphics, fun gameplay, and social features. It was known for its focus on teamwork and collaboration, encouraging players to work together to complete quests and defeat the Cogs. The game was shut down in 2013 after a successful ten-year run, but it has since been revived by a group of fans who have created their own version called Toontown Rewritten.

A Different MMORPG

Toontown Online is based not in the traditional quest, fantasy, or science fiction themes of most MMORPGs. Instead, Toontown is a whimsical virtual world in which Toons, cartoon characters of the 1940s variety, inhabit six neighborhoods. The neighborhoods are happy, colorful places and each is associated with a classic Disney character. As an element of conflict in the game, mean Cogs, out-of-control business robots, have come to town and are ruining this happy environment by making it a black and white city of skyscrapers and businesses. The game enlists players to become Toons to save the town. Toons talk with each other through word balloons and take their world back by using traditional cartoon practical jokes and slapstick comedy such as cream pies, seltzer bottles, and whistle blowers against the Cogs, who have no sense of humor and cannot take a joke. The game was designed mainly for children (7 and up), but adults also enjoyed Toontown's nostalgic elements, humor, and game play.

Toontown's Backstory

Toontown's story begins on the outskirts of the place cartoon characters call "home." On this day, world-famous billionaire Scrooge McDuck decides to pay a visit to his favorite employee, eccentric inventor Gyro Gearloose.

Gyro has posted a warning sign on his laboratory door that says "KEEP OUT." Scrooge ignores it, opens the door, and calls out "Gyro?" He walks pass a vast array of laboratory equipment, test tubes, and microscopes. Gyro is nowhere to be found. "I wonder where Gyro could be?" thinks Scrooge. In the back of Gyro's laboratory, Scrooge is stunned by what he sees and cries out, "Sufferin' catfish! A g-g-giant robot!"

Scrooge then thinks to himself, "Hmm... A giant robot... Perfect... Why, a thing like this could be a really big help to the citizens of Toontown... And make me a big pile of money!"

However, Gyro has left a huge note on the robot that says "DO NOT TOUCH!" Scrooge is upset. "Do not touch?" he thinks, "Phooey! That can't mean me! After all, I paid for it.... Let's get my investment up and running!"

Scrooge proceeds to connect the broken wires – the blue one to the red one. The giant robot instantly comes to life!

"All systems ready!" says the giant robot in a deep voice. Scrooge begins to worry, "Great heavens to Betsy! What have I done?"

His fears are fulfilled as the giant robot stomps toward the control panel, pushes the red buttons, pulls the lever, and manufactures hundreds upon hundreds of evil robots called Cogs. They come in various sizes, shapes, and abilities to inflict evils in Toontown. Scrooge panics, "Oh my heavenly days! This can't be good...".

The story ends with Gyro's invention running amok. Scrooge has placed himself and all of Toontown in danger. Can anyone stop this army of robots? "Toontown needs your help now!"

Becoming a Toon

To save Toontown from the evil Cogs, the player has to become a Toon. Each account holder can create up to six Toons in the virtual world. A menu of characteristics such as height, weight, color, and fashion style are available to make each Toon an individual character that reflects a player's preferences.

Naming characters in games has often been abused, and it is almost impossible to create a filter that would prevent players from using inappropriate names that might be offensive to some of the audience. Instead of relying on an automated "naughty list" filter, Toontown Online employs a name generator that gives a player millions of possible combinations based on a choice of title, first name, and last name from a suggested list. The generated list provides names that are in keeping with the humorous nature of Toontown. To avoid the problem of inappropriate names, players are offered a list of titles and first and last names from which to choose their avatar's name. If the player chooses, they may enter their own name, which goes through client and server-side filters and is reviewed by a Disney customer representative before acceptance.

Once a player has made and named her/his own Toon, they are ready to enter Toontown and meet and play with other Toons. In keeping with the positive, upbeat tone of the site, if Toons join on a special day such as New Year's Day, they are greeted in the playground with a display of fireworks.

Safe and Friendly Socializing

Toontown encourages socializing and incorporated in the game are features that facilitate socialization that is friendly, safe, and fun. Communicating through chat is a necessity in a multiplayer game; in most MMORPGs it is unrestricted. To protect kid's privacy and ensure online safety, Toontown Online features SpeedChat, a menu-based chat system that provided safe player-to-player text interaction. Kids choose what they want to say from an extensive set of preselected context-sensitive words and phrases that automatically adapt to the player's objectives and status in the game. The set menus eliminate game jargon that may not be understandable by new players and helps novice typists who may have difficulty with grammar and spelling. A particular feature is that the phrases are friendly and encourage engagement and cooperation between players.

SpeedChat is sufficient to convey a player's feelings (e.g., happy or sad) and simple thoughts (e.g., follow me, let's play a game) that are enough to play the Toontown game without hindrance. The friendly nature of the word sets helped to overcome shy players' inhibitions. Overall, the lack of open chat helped the players focus more on the gaming tasks at hand rather than spending time on chitchatting and digression.

Open chat is available in Toontown between "true friends." True Friends are those who are friends in actual life and may want to chat more extensively when playing online. To activate open chat between two Toons, a randomly generated secret password that is valid for only 48 h is given to each of them. Friends share their secret password over the phone, via email, or instant messaging; each friend must then enter the correct password in Toontown before it expires. True Friend chat is filtered for inappropriate language and the chat is incomprehensible to other Toons.

In addition to making chatting safe as well as friendly and engaging, Toontown offers many shared activities to help with making friends and becoming a part of the community: there are mini games to play, opportunities to go fishing, and ongoing Cog battles to join. Socializing is encouraged by the simple way in which newbies (newer players) can join play: They could hop on a trolley car and meet other players going to a game or simply walk up to a battle that may be in progress and be instantly included without any chat. Elders (more experienced players) are rewarded when they help out a newbie in battle against the Cogs; because the rewards received in a game are proportional to the contribution made, elders are not penalized in battle when a newbie joins. This positive approach facilitates newer players' inclusion in the gaming community.

Other features were included to make Toontown a friendly environment: Portable holes

allowed players to teleport immediately to wherever their friends are located, there is no player-to-player battling or any opportunity to steal or hoard items, and, instead of getting hurt or dying, Toons become sad and go back to the playground to become happy again.

Collecting and Cooperating to Save Toontown

Toontown Online offers many mini games for the players to win the "jelly beans" necessary to make purchases of cartoon weapons to fight the evil robots. Jellybeans are the main components in the game's system of barter.

Some of the popular mini games are maze, tag, memory, treasure dive, slingshot, ring, cannon, jungle vine, and tug-o-war. Most of these games are action adventure in nature to keep the adrenaline flowing and maintain a quicker pace in the overall mood of Toontown. Although most of the mini games are competitive, there is no "winner takes all" mentality. If the player exerts some amount of effort, chances are he/she will win some jellybeans, although perhaps not as many as the winner. For newbies there is a series of training tasks to follow to learn how to win jellybeans, explore the virtual world, and destroy the evil robots. Toons battled Cogs with cooperation and comic rather than violent action.

Cogs have different names such as Pencil Pusher, or Tightwad, according to their different abilities, and they are classified into different levels according to their power. Regardless of their abilities, high-level Cogs are more dangerous than low-level robots. It often takes simultaneous actions from a team of Toons to destroy a high-level Cog. When fighting against the evil robots or Cogs, Toons need to cooperate with each other.

Once all the Cogs have been evicted from a building and eliminated, the ugly grey building is magically transformed into a happy place with bright vibrant colors. The team of Toons that accomplished this task is rewarded by having each player's Toon name displayed on the wall of fame inside the building. In addition, the top Toons and their accomplishments are announced in The Toontown Online Times daily newspaper.

Toontown Innovation and Panda3D

Toontown Online was designed as "a safe social game that was simple to learn yet challenging to master" (Mine et al. 2003). When released, Toontown proved to be innovative in many ways:

- It provided a safe online environment for children thanks to the Toon name generator, SpeedChat, and True Friends.
- It encouraged both competitiveness (in the mini games) and cooperation (in fighting against evil). There is no "winner takes all" mentality even in a competitive mini game.
- It minimized violence in the gameplay through the use of cartoon slapstick weapons such as cream pies and seltzer bottles instead of guns and swords, and by using robots that are mechanical rather than humans. Because Toons never die, but rather become sad, issues of physical pain, blood, and death didn't arise as they do in adult MMORPGs.

Toontown Online was built on an open-source cross-platform Panda3D game engine created by The Walt Disney Company. Panda stands for Platform Agnostic Networked Display Architecture which provides the portability and flexibility for Toontown to run on any operating system. Built on an efficient low-level C++ engine, Panda3D expressive scene graph architecture gave designers tools for creating diverse and dynamic worlds for Toons to inhabit while its interpreted scripting language gave programmers flexibility to prototype software rapidly and debug game logic quickly.

Public Reception

Although Toontown Online was designed as a nonviolent game alternative for kids aged 7–12, adults enjoyed the game as much as kids did, making Toontown Online family entertainment similar to a Disney theme park where kids and

parents have fun together. The monthly subscription model with reduced rates for longer memberships proved acceptable to the audience and profitable for the company. A basic level of play is available free on the site so anyone interested can make a Toon avatar, enjoy walking about, and play a mini game or two to see if they like the environment. In addition to the online subscription plans, prepaid subscription cards (one or more months) were made available at retail outlets to allow sampling of premium content.

Toontown Online quickly gained enormous popularity with a high retention rate after the initial free three-day trial. In mid-2005, Toontown had nearly 10,000 people playing simultaneously during the busiest times. In May 2007, independent Internet research firm Comscore estimated Toontown Online had nearly 1.2 million users. Disney also produced versions of Toontown Online for the UK, France, Spain, Japan, Southeast Asia, and Brazil.

Cross-References

- ▶ Online gaming scalability
- ▶ Panda3D

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Disorientation

- ▶ Spatial Perception in Virtual Environments

Display Holography

- ▶ Holography as an Architectural Decoration

Distal Pointing

- ▶ Raycasting in Virtual Reality
- ▶ Virtual Pointing Metaphor in Virtual Reality

Distance Matching

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Distant Object

- ▶ 3D Selection Techniques for Distant Object Interaction in Augmented Reality

Distributed Architectures for Online Multiplayer Games

- ▶ Online Gaming Architectures

Distributed Multiplayer Game

- ▶ Distributed Simulation and Games

Distributed Simulation and Games

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Synonyms

Distributed multiplayer game, Simulation, Synchronization

Definition

Distributed game simulation is a single simulation, which has been distributed over multiple processors and interconnected via a network. The game entities are synchronized in a manner, which try to ensure that the game is playable and fair, despite network latencies.

Introduction

Many computer games present dynamically modelled game environments, which are dynamic in the sense that they change over time. Changes to the environment are typically initiated by events, which can be created by users (e.g., players) or other events. Simulation in a computer game uses discrete time, as the state of the environment is inspected in discrete points in time. This is called discrete event simulation. Inspection of the states does not necessarily have to be inspected at even intervals, but when something occurs that can change a state in the system. Events are placed in an event queue and ordered by the timestamp of their scheduled execution. An example can be a simulated airplane, which is scheduled to land at time t, for which an event *landing* is added to the event queue. Time t will be the next point of time when the airplane has to be inspected again. However, if something happens in the system that can affect the plane before landing, then an earlier placed event might have to be removed from the event queue. Game engines run a game loop, which dictates the minimum time step between two sequential events. Typically, game optimizations make sure that only events related to objects which need to be inspected at that time are inspected and they can be also prioritized based on the importance of the object (e.g., visible to player, affect game play fairness, and correctness). In practice that can mean that less important events are placed to an event queue further apart in time.

Game Simulation in Distributed Environment

Sharing of a game environment between multiple players with their own game devices adds another dimension. There is usually some uncertainty between the game (simulation) states in each device, which is caused by the message exchange latency. The impact of this latency increases with the demand of more frequent game state updates. For example, in an ice hockey game, each player plays the game in their own computer, which is modelling the game simulation, and controls one of the ice hockey players. The game state in each computer should not differ too much to make the play experience acceptable.

In distributed simulation, there are two approaches for managing uncertainty and ensuring correctness of the simulation: conservative (Chandy and Misra 1979) and optimistic (Jefferson 1985) approaches. In a conservative approach, each simulation agent (or game client) reports how far in time they have progressed. They can only progress within some preselected time boundaries of each other. Conservative approaches are not generally used in action games because they are limited by the speed of the slowest client (or the longest latency). In optimistic approaches, each client can simulate the game as fast as they can, but if an error is detected they have to do a rollback, i.e., they have to undo things that went wrong in the simulation, and correct game states, which can cause more rollbacks. These synchronization problems can be seen, e.g., as an opponent avatar changing position suddenly. Game interfaces try to hide these

synchronization errors, e.g., by using start movement animations, which can lead to failed action as needed.

As the network is one of the critical resources, it is important to try to limit the frequency of synchronizations and the volume of exchanged messages. Methods like dead reckoning (Pantel and Wolf 2002), in which the next position of an object is estimated from current movement, are used to reduce needed update frequency. Analysis of synchronization problems with their solutions are available for the games Halo: Reach (Aldridge 2011) and Age of Empires (Bettner and Terrano 2001).

Extensive work has been done in standardization to connect distributed simulators, especially related to serious gaming. High-level architecture (HLA) (IEEE Std 1516 2010) is an interoperability standard to integrate a number of separate simulations into one and used, for example, in military war games. An alternative standard is Distributed Interactive Simulation (DIS) (IEEE Std 1278.1 2012).

Conclusion and Discussion

Impact of the network is an aspect that should be considered from the beginning of a multiplayer game design. In many cases in the early 1990s, game developers produced games, which were later decided to include Internet multiplayer possibility. The complexity of adding the multiplayer option turned out to be more challenging than it was pre-seen and typically took considerably more time to get working than was expected. These problems have not disappeared today, and game designers have to consider how the synchronization between the game simulations is done in sufficient way to ensure good user experience and scalability.

Cross-References

- ▶ Secure Gaming: Cheat-Resistant Protocols and Game History Validation
- ▶ Serious Games
- ▶ Virtual World, a Definition Incorporating Distributed Computing and Instances

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Distributed Virtual Environment, DVE

- ▶ Peer-to-Peer Gaming

Diversity in Gaming and the Metaverse

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Synonyms

Cross-culturalism; Cultural diversity; Cyberspace; Digital sports; Electronic sports; Esports; Ethnic inclusiveness; Multiculturalism; Multiverse; Virtual reality

Definition

The metaverse is a digital reality that combines aspects of social media, online gaming, augmented reality (AR), virtual reality (VR), and cryptocurrencies to allow users to interact virtually (Folger 2021).

Gaming or Esports are competitive digital tournaments (sports) held online, in real life, and also in the metaverse.

Diversity (Diversity and Inclusion Definitions) is the range of human differences, including but not limited to race, ethnicity, gender, gender identity, sexual orientation, age, social class, physical ability or attributes, religious or ethical values system, national origin, and political beliefs (n.d.).

Introduction

This entry is a commentary on the current state of diversity in the digital world and what opportunities the future may hold in the new ecosystem (metaverse).

The human fascination with a virtual world is not a new concept. Video games have been around since 1947 (Early history 2021; Wikimedia Foundation 2021) but the first game that really launched the industry can be attributed to physicist William Higinbotham who created a simple tennis game in October 1958 that became a big hit at the Brookhaven National Laboratory open house (Tretkoff 2008; October 1958: Physicist invents first video game n.d.). In the early days, a video game was a computer-generated program intended to deliver fun to the user that was performing certain tasks. Today the scope remains the same, but the level of engagement is almost limitless. From one user interacting with a computer to today's virtual worlds, the digital gaming evolution has moved quickly into our lives with both positive and negative results.

With the rapid growth of the World Wide Web and access to information, people are becoming more educated, more connected, and more informed. Although there still exists a digital divide or gap in access for some demographics, diverse populations are more connected than ever before. People interact globally through many different platforms including social media, communication applications, and online gaming (esports). With a more integrated society, cultural differences come to the surface which allows people to learn about different traditions, values, and belief systems. These tools that connect the world can bring people together based on a common interest, and this is a powerful way to build bridges and discourage prejudice.

Ideally, everyone can play in this virtual world of esports and gaming where they can truly become what/who they want regardless of physical, economic, or other disadvantages. At the heart of esports is an inclusive ecosystem. Unfortunately, the reality turns ugly when people are not accountable for their digital actions. The interconnectivity and the possibility to hide behind a screen can fuel cyber bullying when some people exploit the anonymity of a gamer-tag (a player's chosen name while gaming) to be abusive to others without consequence. Gaming communities tend to be a tight nit group because of their shared passion. The social connection is important and can be difficult for a person that does not fit in with the group. When an ecosystem is not welcoming and safe, it does not breed diversity. Whereas on one side, esports is about entertainment and fun, there is an ugly side of the virtual world that lacks the checks and balances to prevent people from behaving badly. However, a solution may be just around the corner. There are many companies that are working on creating programs that can help solve this issue with a digital identity for every individual. The goal is to develop accountability and regulations, so the virtual world can be safe for everyone as the metaverse becomes more mainstream.

The term metaverse (Frey 2021) was first used in the 1992 novel "Snow Crash" by Neal Stephenson. In 2003, Linden Lab built an on-line platform called "Second Life" where people could create an avatar (digital persona) and have a second life in a virtual world. In 2011, author Ernest Cline gave a then-new interpretation of a virtual world in his novel (Cline 2011) "Ready Player One." Cline tells the story of how a videogame character

comes to life in the year 2045 and therefore owns its position in the virtual world. He imagined what it would be like for a player to experience a transformative participation where the player/character was not anymore just "behind the screen" but was sort of "within the screen." Visionaries had already started putting together the building blocks of this imaginary digital world and soon after mainstream companies pivoted to align with this emerging technology. New decentralized currencies have been introduced as the world started its next phase of a digital revolution. In 2020, while in the midst of a global pandemic, people across the globe were stuck at home with limited ways to socialize, so they turned to the digital world to escape reality. The concept of a metaverse became truly mainstreamed in 2021 when Facebook's parent company changed its name to Meta.

What part diversity can play in all of this? Imagine a completely new world in a digital form created by people from different backgrounds. In this world, everyone will have their own avatar that can perform actions one could have only dreamed of before. Now imagine that all of these avatars have a digital identity, so everyone can feel safe and welcome. The metaverse is an opportunity to create an ecosystem where everyone is equal. It is also a new frontier to explore proof of concept, test new research, or prototype new products to then be reproduced in real life. The opportunities are endless. With the power of connectivity, people from less privileged communities can have a chance of making a mark in a world with a lower barrier of entry. Society has a new chance to do this right and, hopefully, everyone will embrace it. Full inclusivity is now just a click away. Only time will tell.

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Divide

▶ Academic and Video Game Industry "Divide"

DLC

▶ Emotion in Games

Documentary Games

▶ Political Game Design

Dog Technology

▶ Engaging Dogs with Computer Screens: Animal-Computer Interaction

Dogs

▶ Engaging Dogs with Computer Screens: Animal-Computer Interaction

Dōjin Game

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Synonyms

Doujin Game

Definitions

Dōjin games (alternatively romanized as doujin) are digital games made by individuals or small teams of enthusiasts, referred to as dōjin circles. Alongside other media such as manga comics, literature, anime, and music, these games are part of the wider dōjin scene, which originated in Japan and which revolves around a shared appreciation of popular culture.

Overview

Kenkyūsha's New Japanese-English Dictionary (2003) explains the term *dōjin* (同人) as being short for *dōshi-no hito* (同志の人), or "like-minded person, kindred spirit." The word *dōjin* is generally used to refer to small groups (*sākuru, "circles"*) of individuals brought together by their shared tastes in popular culture, who produce self-published works such as literature, manga comics, digital games, literature, and/or music. Although most dōjin producers are hobbyists, some are professional or semi-professional artists, writers, game designers, etc. (Hichibe and Tanaka 2016). Fan works (*nijisōsaku*) based on worlds and characters from popular culture make up much of dōjin scene; yet original works are also common (Lamerichs 2016). A significant proportion of dōjin works are erotic or pornographic in nature (Watabe 2013), with many fan works seeking to extend the fictional worlds of popular culture into the realm of erotic fantasy.

By contrast to Japan's mainstream gaming, which revolves largely around game consoles and to a lesser extent amusement arcades, dōjin games, also referred to as *dōjin sofuto*, are primarily designed for the personal computer (Hichibe and Tanaka 2016). Most of these games belong to one of a handful of typical genres such as visual novels, role-playing games, and scrolling shooters. Thematically and aesthetically, they usually cater to established niches such as *bishōjo* (male-oriented games featuring beautiful girls), *otome* (games for young women focusing on relationship building, usually with a handsome male character), *yaoi* (games depicting homoerotic relationships between male characters, but generally intended for female consumption), and so on.

While there are many dōjin shops in Japan, specializing in dōjin manga (dōjinshi), games, and music, dōjin works can also be found in mainstream manga and game shops. However, the most visible venue for dōjin work dissemination is the semi-annual Comic Market convention in Tokyo (Lam 2010). Smaller local events and conventions also play an important role.

Despite originating from Japan, dōjin culture has extended to other countries in the region such as China (Si 2015), Taiwan (Chiang and Lo 2012) and South Korea (Yoon 2015). Moreover, it has had considerable cultural impact in the West as well, leading creators to appropriate some of its genres and conventions (Lamerichs 2016).

History

While dōjin games are a relatively recent addition to the wider dōjin culture, the culture itself has its origins in the late nineteenth–early twentieth century dōjin literary circles (Morishita 1980). These circles produced self-published literary magazines such as *Bungakukai* and *Shinshichō*, which were

highly influential in Japan's pre-war literary scene (Encyclopedia Nipponica 1994). In the post-war period, some of these magazines began to include manga; dedicated dōjinshi manga magazines, such as Shōtarō Ishinomori's *Bokujū Itteki*, were also increasingly published (Kálovics 2016). Self-published manga gradually became a fixture at science fiction conventions, and in 1972, *Nihon Manga Taikai*, a dedicated manga convention, was held for the first time, with some booths selling dōjinshi magazines (Iizuka 2017).

However, the biggest impetus to the development of dōjin culture was the emergence of the Comic Market (or Comiket) in 1975 (Lam 2010). Whereas the first grassroots convention attracted 32 dōjin circles and about 700 attendees, today Comiket brings together around 500,000 participants on average who buy and sell dōjin manga, novels, and games, as well as engage in cosplay and other activities.

The appearance of home computers such as MSX and NEC PC-88 in the 1980s enabled hobbyist developers to create their own computer games, which began to find their way into dōjin culture. Visual novel *Ningyo no Namida* ("The Mermaid's Tears"), released in 1984 by Teikoku Soft, is considered to be the first dōjin game to be exhibited at a Comiket. By the end of 1980s, computer games had become a staple at dōjin conventions. In 1988, *Pasoket*, a spinoff of Comiket focusing on games, began to take place in cities across Japan on a monthly basis (Hichibe 2013).

More recently, the advent of digital distribution has further widened the reach of dōjin games, many of which are now sold (or distributed for free) online, with an increasing number found on global distribution platforms such as Steam and Apple's App Store (Hichibe and Tanaka 2016).

Specificity and Significance

Dōjin games are often compared to the Western phenomenon of indie games (Picard 2013; Consalvo 2016), but there are important differences between the two. While indie games stress the artistic independence of their creators and distance themselves from mainstream gaming (Garda and Grabarczyk 2016), many dōjin games are in fact fan works based on mainstream games. Additionally, dōjin games are one part of a close-knit transmedia continuum also including manga, anime, literature, music, etc.

The lack of opposition towards mainstream gaming and the close integration with other media means that some dōjin games achieve wide recognition beyond both the niche of dōjin culture and the cultural form of game. One example is *Higurashi no Naku Koro ni* ("Higurashi: When They Cry"), which started in 2002 as a horror visual novel sold at the Comic Market but has now evolved into a transmedia franchise comprising an anime series, a manga, a live action film, multiple novels, and an action game (Wheeler 2011), reflecting how interconnected Japan's "media mix" (Steinberg 2012) is.

The integration of dōjin content with mainstream media and major distribution networks is also interesting from another perspective: that of copyright. The co-existence of mainstream works and fan-made "parodies" (often of an erotic nature) on manga and game shop shelves can hardly be explained through the Western copyright framework. Such a status quo, albeit precarious from a legal standpoint (Noppe 2010), offers a vision of how copyright holders can interact with fan producers – and how creativity can emerge at the intersection of independent production and fandom.

Cross-References

▶ Indie Game
▶ Visual Novel

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Domain-Specific Choices Affecting Design Effort in Gamification

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Synonyms

Choices in games; Edutainment; Game design; Game production effort; Gamification

Definitions

Gamification: It is the process of modifying an activity which does not include elements of a game, to allow the performer of the modified activity to (i) improve knowledge or skill using the feedback from the mechanism built into the modified activity while being entertained through text, pictures, animations, video, or audio, (ii) dynamically earn rewards, (iii) win, or (iv) be dynamically ranked, by fulfilling relevant conditions, such that the overall experience of the performer of the modified activity is different from the experience of getting points, grades, certificates, gifts, payments, or prizes based on paid/volunteer work, shopping, or assessment similar to that in schools or colleges.

Introduction

Santos and others (Santos et al. 2018) report on how requirements analysis, test planning, test design, test execution, and test closure for computer games differ from these activities for software which is not a game. Though there is lot of theoretical and empirical work on estimating the effort needed for development, testing, and maintenance of software, estimation of effort for designing, developing, and testing computer

games remains underexplored. Identifying domain-specific choices affecting game-design effort has several uses. Design influences the effort for development, testing, and documentation. This affects budget of the project, quality of the game, and the temporal schedule of game production. Indicators of game-deign effort can be used in predicting if the game can be produced while meeting budgetary, temporal, and quality-related requirements. This helps in adjusting scope of the game. Since design of computer games is usually open-ended because of game design being highly creativity-based, theory of computer games continues to evolve. Identifying domain-specific choices in design of computer games is also useful for refining the theory of computer games that captures breadth, depth, and diversity in this field. This article identifies many of the key domain-specific design choices in games for motivating people, teaching people to recognize objects, and teaching a language, engineering design, computer programming, or algorithm development, and shows how identifying domain-specific choices in game design can be useful.

Gamification for Motivating

Bianchini and others (Bianchini et al. 2016) present a web-based mobile platform for e-participation of administrators and citizens. This platform allows citizens and administrators to submit and share problems, initiatives, and solutions. Other citizens within the same municipality can add their own solutions. Citizens obtain points for submitting proposals and solutions. A citizen gets an extra point for each detail added to the solution and each vote received on the solution. Administrators can award additional points. *Leaderboard of New Solutions*, *Leaderboard of Completed Solutions*, *Leaderboard of Citizens*, and *Leaderboard of Proposals* are used to assign black, silver, and gold medals to citizens. An administrator can assign a blue medal. Medals enable citizens to change their level. Level 1 has interested citizens. Level 2 has active citizens. Level 3 has distinguished citizens. The governance of the municipality may publicly reward the winner of *Leaderboard of Distinguished Citizens* each year.

Butler and Ahmed (2016) present a game to motivate students to achieve computer-science-learning goals. The first level of the game introduces stacks and queues. The second level of the game includes Selection Sort, which is a sorting algorithm. A player is a cadet at a space academy and has his/her own robot to control and customize while performing missions.

A list of key design choices in gamifying the process of motivating people to achieve a goal is provided next.

(i) Goals for which to motivate the player, e.g., blood donation, monetary donation, studying for an international competitive examination, volunteering at a retirement home, and volunteering at a public library
(ii) Number and types of activities that directly motivate the player to achieve the relevant goal by issuing rewards that the player can show others if he/she wishes (e.g., an email sent to friends or relatives of the player when the player donates the correct quantity of blood at a location where it is most needed is a reward that directly motivates the player to donate blood in virtual world, and it is hoped that the player will be motivated to donate blood in the real world after playing this game)
(iii) Number and types of activities that indirectly motivate the player to achieve the goal, e.g., taking a tour of a hospital in digital world showing suffering of patients in need of blood
(iv) Number and types of activities to include to teach undesirable consequences of overdoing the activities that the game motivates the player to perform

Gamifying Object Recognition

Teaching players to recognize objects has numerous advantages, e.g., players can use the ability to

recognize objects in a domain in shopping, repairing machines, supplying parts, and reporting diagnosis of dysfunctional machines. A list of key design choices in gamification of object recognition is provided next.

(i) Types of objects to include in the game, e.g., plants and animals
(ii) Objects of chosen types to include in the game, e.g., cabbage, spinach, and carrots
(iii) Shapes, designs, colors, sizes, and orientations of objects, e.g., red cabbage and green cabbage
(iv) Lighting conditions in the region containing the object/objects to be recognized
(v) Whether to simultaneously show multiple objects for the player to recognize or not
(vi) Whether to show a part of the object to be recognized instead of the entire object
(vii) Whether to allow objects to touch each other or partially block the view of other objects or not, if multiple objects are to be shown simultaneously
(viii) Whether to show damaged objects or not
(ix) Types of damage to show
(x) Whether to include objects that are not damaged but have an undesirable appearance or not, e.g., cups with dust that can be removed by washing
(xi) Whether to include irrelevant objects or not
(xii) Maximum number of objects to show simultaneously
(xiii) Number of images of an object to show
(xiv) Whether to show multiple images of an object simultaneously or sequentially
(xv) Whether to show three-dimensional version of an object or its 2D projections, e.g., view from top, view from bottom, view from front side, and view from rear side
(xvi) Types of clues and number of additional clues to give to help in recognizing the object, e.g., sound made when the object falls on wood or concrete, changes in the object with variation in temperature, and changes in the object due to chemical reactions

Gamifying Language Learning

A gamification of Mandarin learning is presented in (Heryadi and Muliamin 2016). They divided the learning material among the following categories: (i) Greetings, (ii) Family, (iii) General conversation, (iv) Colors, (v) Numbers, (vi) Days and months, (vii) General vocabulary, (viii) Food, and (ix) Animals.

A list of key design choices in gamification of language learning is provided next.

(i) Languages to teach
(ii) Native languages to include in the game
(iii) Number of letters or symbols of the alphabet to show at a time
(iv) Number of words to show at a time
(v) Number of sentences to show at a time
(vi) Number of words in a sentence
(vii) Order in which to show letters, symbols, words, or sentences
(viii) Whether to show incomplete words or sentences or not
(ix) Number of letters to exclude from words and number of words to exclude from sentences, when the player is expected to enter missing letters or words
(x) Number of writing styles to use to generate letters, symbols, words, and sentences
(xi) Number and types of accents in the audio clips containing pronunciations of letters, symbols, and words
(xii) Minimum number of letters in words, minimum number of words, minimum number of sentences, minimum number of words in individual sentences, or the lower limit on the total number of words the player is expected to type or speak, if the player is asked to type or speak as much as possible in the given time
(xiii) Number of irrelevant symbols, letters, words, pictures, or sentences to include for the player to identify the relevant ones
(xiv) Types of pictures and number of pictures to include if the player is expected to match them with text, type relevant text, or speak in response to the shown picture/pictures

(xv) Number and types of pictures to include if the player is expected to order them based on the words in the given sentence or based on the given sentences
(xvi) Number and types of words whose meanings to include to create a verbose text that the player is expected to make concise by replacing the meanings with corresponding words
(xvii) Number of words, sentences, and clusters, and clustering criteria, when the player is expected to group words or sentences based on the given criteria, e.g., putting synonyms together, putting words or sentences related to airports together, etc.
(xviii) Number of clusters and number of words or sentences in individual clusters, when the player is expected to identify the criteria used to create the clusters
(xix) Number and types of words, sentences, or paragraphs to include in the text that the player is expected to summarize
(xx) Minimum and maximum number of characters, words, or sentences in the player's answers to free-response questions
(xxi) Themes for free-response questions

Gamifying Engineering Design

A list of key design choices in gamification of engineering design is provided next.

(i) Whether to expect the player to design an entire product or a part of it
(ii) Products and parts to design fully or partially
(iii) Number of design steps to show to the player at a time, if the player is taught by having him/her reorder the given steps
(iv) Number of irrelevant steps to show to the player at a time, if the player is taught by having him/her remove irrelevant steps from the given steps
(v) Number and types of mistakes to introduce within individual steps, if the player is expected to correct mistakes in individual steps, e.g., incorrect choice of materials, incorrect assumptions, incorrect units, and incorrect variables, constants, and mathematical operators in equations
(vi) Number and types of steps to exclude, if the player is expected to detect that some steps are missing, and is expected to provide them
(vii) Amount and types of information to exclude from individual steps if the player is expected to detect incompleteness within individual steps and make the steps complete by providing the missing information
(viii) Number and types of choices to provide to the player at a time when the player is taught to design by having him/her make choices incrementally
(ix) Number and types of designs or design steps to include to have the player rate, classify, or order them
(x) Number and types of design questions and number and types of answers to include when the player is expected to match questions with answers
(xi) Whether to limit the game to teaching to produce feasible designs or include optimal designs too
(xii) Factors to include besides safety and durability, e.g., manufacturability, sustainability, and cost
(xiii) Number and types of differences to introduce between two designs or steps, when the player is expected to compare them and find as many differences as possible
(xiv) Number and types of facts about designs to include if short questions are to be posed to the player
(xv) Number of products or parts to include in the set of options when the player has to choose the products or parts the given design steps are relevant to, from the given options
(xvi) Number and types of opportunities to include in a correct design for the player to detect and improve the design
(xvii) Number and types of steps in the design of different products or different parts to present to the player as if all of these steps are

for designing only one product or only one part, for the player to associate the steps with different parts or products

(xviii) Number and types of designs or design steps to present to the player when the player is expected to identify why they are ordered, rated, or clustered the way they are in the challenge

Gamifying Algorithm Development

A list of key design choices in gamification of algorithm development is provided next.

(i) Types and number of algorithms to include in the game

(ii) Whether to design challenges based on an entire algorithm or a part of it

(iii) Whether to expect the player to design an entire algorithm or a part of it

(iv) Whether to expect the player to analyze an entire algorithm or a part of it

(v) Type of analysis to include in a challenge (e.g., completeness, optimality, time complexity, and space complexity)

(vi) Number and types of steps of an algorithm to show to the player at a time, for analyzing them

(vii) Number and types of subtasks within an algorithm to present to the player for him/her to provide a part/parts of the algorithm

(viii) Number of steps of an algorithm to show to the player at a time, if the player is taught by having him/her reorder the given steps

(ix) Number of irrelevant steps to show to the player at a time, if the player is taught by having him/her remove irrelevant steps from the given steps

(x) Number and types of mistakes to introduce within individual steps, if the player is expected to correct mistakes in individual steps, e.g., incorrect choice of data structures, syntactic errors, incorrect mathematical operators, variables, or constants, and incorrect type of statement

(xi) Number and types of steps to exclude, if the player is expected to detect that some steps are missing, and is expected to provide them

(xii) Amount and types of information to exclude from individual steps if the player is expected to detect incompleteness within individual steps and make the steps complete by providing the missing information

(xiii) Number and types of choices to provide to the player at a time when the player is taught to design an algorithm by having him/her make choices incrementally

(xiv) Number and types of algorithms or steps in algorithms or steps in algorithm analysis to include, and have the player rate, classify, or order them

(xv) Number and types of design or analysis questions and number and types of answers to include, when the player is expected to match questions with answers

(xvi) Whether to limit the game to teaching to design sound algorithms or include algorithm optimization too

(xvii) Factors to include besides soundness, e.g., ease of modification to handle extra inputs or inputs of different types, ease of modification to produce a solution meeting additional or different requirements, and ease of modification to find more than one solution or count the number of possible solutions

(xviii) Number and types of differences to introduce between two designs or steps, when the player is expected to compare them and find as many differences as possible

(xix) Number and types of facts about algorithms to include if short questions are to be posed to the player

(xx) Number of problems to include in the set of options when the player has to choose the problems the given algorithm steps are relevant to

(xxi) Number and types of opportunities to include in a correct algorithm or analysis of an algorithm, for the player to detect and improve

(xxii) Number and types of steps from different algorithms or their analyses to present to the player as if they are steps for only one algorithm or its analysis, for the player to associate the steps with corresponding algorithms or analyses
(xxiii) Whether to include parallel algorithms or not
(xxiv) Number and types of steps or algorithms to present to the player to parallelize
(xxv) Number of parallelizable steps to include along with inherently-sequential steps, when the player is expected to classify each step as parallelizable or inherently sequential
(xxvi) Number and types of algorithms or their parts to present to the player when the player is expected to identify why they are ordered, rated, or clustered the way they are in the challenge

Gamifying Programming

Carreno-Leon and others (Carreno-Leon et al. 2018) present the use of gamification in a course on introduction to programming. In the first level, the student is given only those cards that appear in solution. In the second level, the student is given more cards with pseudocode fragments than needed, but the number of cards needed in solution is disclosed. In the third level, the student is given more cards than needed and not told how many are needed in solution.

A list of key design choices in gamification of programming is provided next.

(i) Programming paradigms
(ii) Programming language/languages
(iii) Features of programming language/languages to cover in the game
(iv) Number and types of programming tasks
(v) Whether to design a challenge based on an entire program or a part of it
(vi) Whether to expect the player to provide an entire program or a part of it
(vii) Whether to expect the player to analyze an entire program or a part of it
(viii) Types of program analysis to include in a challenge (e.g., guarantee of finding a solution, optimality, dealing with invalid inputs, comments for understanding and modification, running time, and memory needed)
(ix) Number and types of steps of a program to show to the player at a time, for analyzing them
(x) Number and types of subtasks fulfilled by a program to present to the player for him/her to provide the corresponding part/parts of the program
(xi) Number of steps of a program to show to the player at a time, if the player is taught by having him/her reorder the given steps
(xii) Number of irrelevant steps to show to the player at a time, if the player is taught by having him/her remove irrelevant steps from the given steps
(xiii) Number and types of mistakes to introduce within individual steps, if the player is expected to correct mistakes in individual steps, e.g., incorrect choice of data structures, syntactic errors, incorrect mathematical operators, variables, or constants, and incorrect type of statement
(xiv) Number and types of steps to exclude, if the player is expected to detect that some steps are missing, and is expected to provide them
(xv) Amount and types of information to exclude from individual steps if the player is expected to detect incompleteness within individual steps and make the steps complete by providing the missing information
(xvi) Number and types of choices to provide to the player at a time when the player is taught to write a program by having him/her make choices incrementally
(xvii) Number and types of programs or steps from programs or steps from program analysis to include, to have the player rate, classify, or order them
(xviii) Number and types of design, implementation, or analysis questions, and number

and types of answers to include, when the player is expected to match questions with answers

(xix) Whether to limit the game to teaching to write correct programs or include program optimization too

(xx) Factors to include besides correctness, e.g., ease of modification to handle extra inputs or inputs of different types, ease of modification to produce a solution meeting additional or different requirements, ease of modification to find more than one solution or count the number of possible solutions, ease of modification to handle other data structures, and ease of rewriting in a different programming language

(xxi) Number and types of differences to introduce between two programs or steps from programs, when the player is expected to compare the two and find as many differences as possible

(xxii) Number and types of facts about programming to include if short questions are to be posed to the player

(xxiii) Number of problems to include in the set of options when the player has to choose the problems the given program steps are relevant to

(xxiv) Number and types of opportunities to include in a correct program or correct analysis of a correct program, for the player to detect and improve

(xxv) Number and types of steps from different programs or their analyses to present to the player as if they are steps from one program or its analysis, for the player to associate the steps with corresponding programs

(xxvi) Whether to include parallel programs or not

(xxvii) Number and types of steps or programs to present to the player to parallelize

(xxviii) Number of parallelizable steps to include along with inherently-sequential steps, when the player is expected to classify each step as parallelizable or inherently sequential

(xxix) Number and types of programs or their parts to present to the player, when the player is expected to identify why they are ordered, rated, or clustered the way they are in the challenge

Usefulness of Identifying Domain-Specific Choices

Domain-specific choices like the ones we identified for six domains, directly or indirectly affect the effort needed to design characters, actions, feedback, rules, challenges, hints, rewards, punishments, gaming world, challenge-adaptation mechanisms for keeping the player motivated and interested, surprises, levels, fairness-enforcement mechanisms, cheating-detection mechanisms, elements relevant to players with special needs, and a multiplayer version. They also directly or indirectly affect the effort needed for localization. Identifying domain-specific choices is useful in several ways. These choices allow us to use counting techniques from discrete mathematics to quantify some components of the gaming experience. Identifying these choices allows us to compare them to know which choices have a bigger impact on the effort needed for game design, development, and testing. This helps in deciding which choices to use. Identifying domain-specific choices can be useful in speeding up game design, development, and testing, by reusing design, code, and test plans of a game from domain D' to create a game in domain D'' when D'' and D' have similar domain-specific choices.

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Dopamine

▶ Video Game Trolls and Dopamine Withdrawal

Doujin Game

▶ Dōjin Game

Down Syndrome

▶ Computer Games for People with Disability

DSDV

▶ Simulation and Comparison of AODV and DSDV Protocols in MANETs

Dynamic Difficulty Adjustment

▶ Meta Artificial Intelligence and Artificial Intelligence Director

Dynamic Game Balancing

▶ Meta Artificial Intelligence and Artificial Intelligence Director

Dynamic Music

▶ Adaptive Music

Dynamic Music Generation: Audio Analysis-Synthesis Methods

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Synonyms

Adaptive music systems; Audio collage; Audio mosaicing; Concatenative sound synthesis; Interactive music systems

Definitions

Dynamic music generation systems create ever-different and changing musical structures based on formalized computational methods. Under scope is a subset of these methods which adopt musical audio as a strategy to formalize musical structure which then guides higher-level transformations to be synthesized as new musical audio streams.

Introduction

Technologies which adhere to nonlinear, as opposed to fixed, storytelling are becoming pervasive in the digital media landscape (Lister et al. 2003). In this context, methods for dynamically generating music have been prominently and

increasingly adopted in games, virtual and augmented reality, interactive installations, and 360 video. Their adoption is motivated by a wide range of factors from computational constraints (e.g., limited memory) to enhanced interaction with external actuators and artistic endeavor.

Dynamic music generation systems are typically driven by formalized or algorithmic methods whose history is interleaved with modern computing (Nierhaus 2009). This article reviews a subset of these systems which adopt musical audio as a source to formalize musical structure algorithmically, which is then used to guide the generation of new musical streams by synthesizing sub-audio clips from the musical audio source – an approach addressed as musical audio analysis-synthesis.

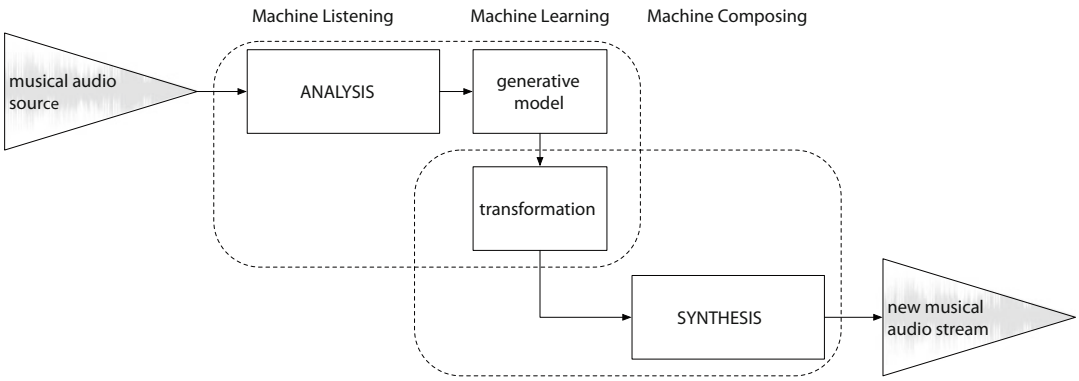
The remainder of this entry details a typical architecture of a generative musical audio analysis-synthesis system (section "From Sound to Musical Audio Analysis-Synthesis Systems") and presents an overview of its applications scenarios (section "Applications").

From Sound to Musical Audio Analysis-Synthesis Systems

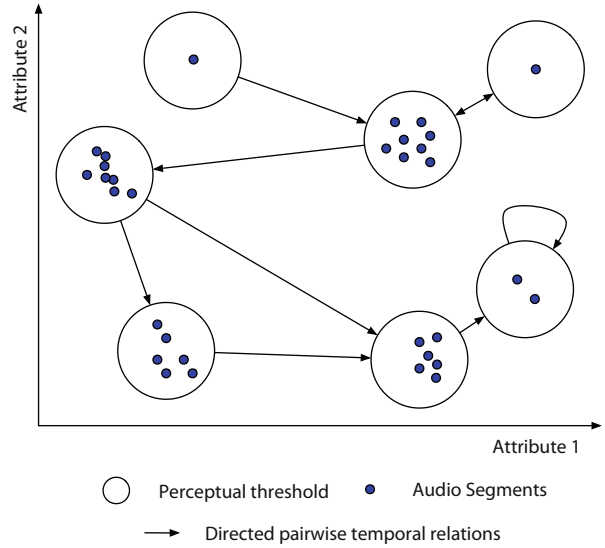
Audio analysis-synthesis methods break down a sound into some essential, measurable attributes (e.g., amplitude or pitch) to guide *sound* transformations during (re-)synthesis (Jehan 2005). Historically, these transformations exist at the sample level and follow an adaptive audio effect architecture (e.g., compression) (Verfaille and Arfib 2001). Recent advances in the hierarchical analysis and generation of musical audio structure have expanded the transformations beyond the sample level towards *music* processing (e.g., automatic remixing).

Analysis-synthesis systems for dynamic generation of musical audio mimic fundamental perceptual and cognitive human functions in a threefold component architecture of machine listening, learning, and composing (see Fig. 1). Machine listening and learning are two intertwined components which primarily adopt bottom-up (or content-driven) processing methods to infer hierarchical structure from audio samples. It comprises two main tasks: multilevel (beat, downbeat, phrase, and section) segmentation and the description of its temporal structure. Inferred information tends to be represented as graphs, whose nodes represent segmented musical structures, and directed pairwise links their temporal relations (see Fig. 2). The resulting representation provides a robust means for computational structure discovery, notably by finding redundant information across the temporal structure which can be clustered according to some (perceptually guided) similarity metric (see Fig. 2).

Typically, each node or segmented musical audio structure is represented in the system by a *feature vector*, i.e., a set of numerical features that result from measurable musical attributes, such as pitch, loudness, and percussiveness. The choice of such attributes, the metrics used to compare them,



Dynamic Music Generation: Audio Analysis-Synthesis Methods, Fig. 1 Architecture of a musical audio analysis-synthesis system for dynamic generation



Dynamic Music Generation: Audio Analysis-Synthesis Methods, Fig. 2 Illustration of a graph model of musical audio structure. The space is defined by (perceptual) attributes (reduced in this illustration to two dimensions). Musical audio segments are understood as data points, represented as circles, whose locations are defined by their attributes in the descriptor space. Small segment distances denote higher (perceptual) similarity in the descriptor space. The circumferences define a perceptual threshold used to cluster similar-sounding segments

and the perceptual threshold used to define the maximum degree of dissimilarity among segments are crucial to the graph design. All these variables are commonly set manually by the users due to their subjective nature and implications in the resulting musical output of the system (i.e., synthesis). To a certain extent, the choice of such variables is akin to the role of sketches and raw material in the compositional process. For a comprehensive comparison of these variables and their implications in the musical results, please refer to Norowi et al. (2017).

If the resulting structural model has sufficient redundancy, machine composing can then traverse the directed links of the graph to create ever-different and changing musical streams which retain the (higher-level) structure of the audio source captured by the model. The output of an analysis-synthesis systems is *musical collages* made of rearranged segments or audio snippets from the original or source audio. The structure of the output musical audio can be understood as a variation of particular features temporal evolution of the source, thus retaining some level of similarity while allowing its indeterminate temporal expansion.

Applications

We present a user-centered perspective of applications for dynamic generation of musical audio through analysis-synthesis approaches. Our twofold fuzzy categorization is rooted in the nature of processed signals and distinguishes (natural or synthetic) sound textures and soundscapes from music. A distinction is made concerning the structure of the audio signal content (e.g., noisy vs. pitched or nonmetric vs. metric) rather than any discrimination based on artistic merit, since both categories (music and soundscapes) can be understood as the product of creative-oriented practices.

The generation of sound textures and soundscapes using analysis-synthesis methods has been applied in audio postproduction for television and film as well as in sound design for games and interactive installations. It mostly tackles the pervasive problem of extending a given audio clip in postproduction whenever the prerecorded audio does not cover the entire duration of a scene (Frojd and Horner 2007; Bernardes et al. 2016). Moreover, some analysis-synthesis soundscape systems also enable to procedurally generate highly controlled nuances that match

external actuators (Bernardes et al. 2013; Schwarz and Schnell 2010). For example, in a game engine, the player behavior can be mapped to soundscape parameters, such as density of events and spectral richness, to enhance the playability through symbiotic relations across modalities.

The generation of music using analysis-synthesis methods has been mainly applied as (online) performance or (offline) computer-assisted composition tools. In the first scenario, it has been highly explored in interactive music systems for human-machine improvisation, where co-improvising machines aim to capture and emulate the musician's style (Schwarz et al. 2006; Assayag et al. 2006; Surges and Dubnov 2013; Pachet et al. 2013; Einbond et al. 2016). The second scenario has been highly explored to guide the search for variations of a given musical audio excerpt in the realm of entertainment technologies or composition of a given user-defined musical audio (Jehan 2005; Bernardes et al. 2013; Lamere 2012; Davies et al. 2014).

Cross-References

- ▶ Audiogame
- ▶ Procedural Audio in Video Games
- ▶ Sonic Interactions in Virtual Environments

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Dynapenia

- ▶ Computer Games for People with Disability

Dyscalculia

- ▶ Computer Games for People with Disability

Dysgraphia

- ▶ Computer Games for People with Disability

Dyslexia

- ▶ Computer Games for People with Disability

E

Earphones

► Immersive Auralization Using Headphones

Editor Architecture

► Decoupling Game Tool GUIs from Core Editing Operations

Education Model

► Design Framework for Learning to Support Industry 4.0

Education Pedagogy

► Design Framework for Learning to Support Industry 4.0

Educational Game

► MEEGA+, Systematic Model to Evaluate Educational Games
► Unified Modeling Language (UML) for Sight Loss

Educational Game Abzû and the Lens of Fun Learning

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Synonyms

Abzû; Educational games; Fun learning

Definition

Educational games – Games that are explicitly designed with educational purposes by helping players learn a concept, a historical event, or a skill as they play.

Lens of fun learning – A critical thought process by applying the concept of fun learning in scrutinizing or analyzing a game.

Learning should be fun. How does an educational game like Abzû hold up when scrutinized by the lens of fun learning? Released in 2016, Abzû is an adventure video game developed by Giant Squid Studios and published by 505 Games for PlayStation 4, Xbox One, Nintendo Switch, and Microsoft Windows. Abzû is named after the freshwater god in the Ancient Mesopotamian religion (Butterworth 2016; Gaston 2016; McElroy 2016; Nava 2016).

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Abzû is similar to Journey – a 2012 indie video game developed by thatgamecompany and published by Sony Computer Entertainment for PlayStation 3 that year. Like Journey, the player starts the game waking up in a strange place without any memory. So the player starts exploring to find something that will help tell them who they are and why they are there. The major difference between Abzû and Journey is the environment. In Journey, the player is on a planet with a barren desert, whereas in Abzu the planet is completely covered in water.

In the beginning the player sees a giant area of water, and there is almost no land in sight except for a few islands here and there. The camera then begins to zoom in on what appears to be a scuba diver floating with his/her face in the water. At maximum zoom, the scuba diver wakes up, looks around, and then decides to dive under to explore. While traveling the diver meets many different types of fish, even ones that are said to be extinct. The types of fish are based on tens of thousands of real-life marine creatures. Their movements are modeled after the behavior of real fish. Artificial intelligence is used to create real-time interaction among marine animals, the diver, and the environment.

The player soon begins to notice that there are not many fish and to wonder where they could be. When the player encounters a coral reef-type object and interacts with it, the object begins to summon some fish back into the sea. As the player continues the adventure and interacts with different objects in a given area, it brings it back to life by restoring all the fish in that area of the game. The reason the fish were gone was because they were killed off by a giant evil robotic otherworldly being. Once the robot is destroyed at the end of the game, the entire ocean and its marine life is fully restored to peace and harmony.

Through the lens of fun learning, we ask ourselves what parts of a game are fun and conducive to learning and what parts need to be more fun and more conducive to learning. In Abzû, a player learns about the sea and marine life at the minimum. The game makes it fun to explore. The player can swim around in current streams with all the fish, look through caves, and explore the unknown sea where they woke up in. The game also teaches about environmental protection. When there is no pollution, the player can search under deep sea. However, when the water is polluted, the player could only see the shallow areas. Toxic water also kills all the fish that live in the affected areas.

The graphics in the game is quite pleasing in spite of limited budget on animation from a game development company. Nevertheless, it would be more fun if there are more ways to interact with the fish in addition to sonar chimes and being able to grab onto large marine animals and ride them for a short distance. All in all, Abzû is a good and elegant exemplification of a well-designed game when scrutinized with the lens of fun learning.

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Educational Games

▶ Educational Game Abzû and the Lens of Fun Learning
▶ Games in Science
▶ Transformational Games

Educational Simulation

▶ Immersive Technologies for Medical Education

Educational Virtual Reality Game Design for Film and Animation

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Synonyms

AR: Augmented reality; DEG: Digital educational game; GBL: Game-based learning; VR: Virtual reality

Definition

This article examines the design methodology of the educational VR game *Cinevoyage*, which was designed by the authors, both experienced as instructors and creators in film and animation and educational game design industries. *Cinevoyage* is designed as an educational tool for filmmaking and animation students with the aim of enhancing their knowledge and skills on *cinematic storytelling*. In this article the term cinematic storytelling refers to telling a story with moving images with respect to disciplines like scriptwriting, film grammar, cinematography, and editing. Thus, any kind of film and digital video making and drawn or computer-generated animations can be considered as a product of cinematic storytelling, if the created content is aimed at telling a story in any way, which can create emotional responses in the audience. Educational institutions teaching cinematic storytelling in any form attempt to build a curriculum that teaches certain fundamental concepts to their students. However, like in any art style, there have always been revolutionary artists who broke the existing rules and created new concepts and methodologies in certain artistic disciplines. It is mostly observed that those were the ones who knew the existing concepts and former works very well and therefore were successful in creating new ones. The educational VR game *Cinevoyage* is designed to be a supporting tool for those educational institutions which aim to transfer the general knowledge and skills on cinematic storytelling to their students, who might become the creative artists of the future.

The term *Digital Educational Game (DEG)* refers to any kind of digital game that is designed with the purpose of educating the player in a specific context (Connolly 2012). The design methodologies, the platforms they are built for, or their genres can differentiate from one DEG to another significantly. Another term *serious games* is also used commonly as an alternative to digital educational games. But serious games imply mostly business-related simulations with gamified elements (George 2017). Therefore, DEG is the preferred term within this article to describe the educational VR game *Cinevoyage* and other games that inspired its design process.

Game-Based Learning (GBL) refers to any kind of learning activity that is supported with game mechanics (Connolly et al. 2008). These games or gamified learning experiences do not necessarily have to be in digital formats (Prensky 2001). In recent years, GBL refers to the usage of both DEGs and analog games for educational purposes. These games can differ from each other in great aspects. *Cinevoyage* is an attempt to introduce GBL approach to educational institutions that aim to teach cinematic storytelling.

Virtual Reality (VR) refers to the technology and the audio-visual products that present an alternative simulated reality to the user. The technology of VR is rapidly changing but within this research, VR refers to a sensory deception within audio-visual field by using specifically built headsets. The degree of immersiveness and suspense of disbelief in VR experiences might differ in great aspects depending on many factors. Some of these factors are the processing power of the supporting computer systems, the field of view of the headsets, or the audio-visual design of the virtual world.

Introduction

As educational technologies become more accessible to the masses, more scholars and designers from various disciplines are motivated to design efficient DEGs in learning environments (Garris et al. 2002). However, it is important to keep in mind that media created for educational purposes does not guarantee a better learning outcome than the traditional teaching approaches. The famous debate between the scholars Clark and Kozma hints that it is the duty of every responsible instructional designer to ask the question whether the same educational objective can be reached efficiently without the use of expensive educational media (Clark 1994, pp. 22–23). Wouters et al. (2009) suggested that the learning outcomes, which can be attained with educational games can be classified in four different ways. These are cognitive learning outcomes (divided into knowledge and cognitive skills), motor skills, affective learning outcomes and communicative learning outcomes. As demonstrated in Bonde et al. (2014), a virtual reality educational game can increase the motivation and can be effective in achieving these learning outcomes if the media usage is combined with traditional lectures with instructors (p. 696).

This article gives an overview of the research, design, and ongoing development processes of an educational VR game *Cinevoyage*, which is the result of a master's thesis study from game design department. The objective of the game is to increase the knowledge of the students on film grammar, frame composition, storyboard creation, mise-en-scène and to improve their skills on working with professional cameras and lighting equipment under real life-like shooting conditions. For this purpose, this article reviews the design methodologies and opinions of researchers, filmmakers, and game designers on how to transfer cinematic storytelling knowledge to students in a more effective and fun way through a DEG.

Research Question

What would be the most efficient game design solution for an educational VR game, with the purpose of increasing the knowledge of the students on film history, visual language, mise-en-scène and improving their skills on working with professional cameras, lighting equipment, and other crew and cast members under real life-like shooting conditions?

Overview

The design methodology of the educational VR game *Cinevoyage* is constructed from six different DEG design methodologies. These studies are: "The FIDGE Model" (Akilli and Cagiltay 2005); "Narrative GBL objects for story-based DEGs" (Göbel et al. 2009); "Tools and methods for efficiently designing serious game" (Marfisi-Schottman et al. 2010); "A New Methodology of Design and Development of Serious Games" (Barbosa et al. 2014); "Design methodology for educational games based on interactive screenplays" (Prieto et al. 2015); "Development of design heuristics for DEGs for school children of 7 to 11 Years Old" (Khanana 2016). A summary of each methodology and how they were used during the design process of *Cinevoyage* is presented in the methodologies section.

Overall design of *Cinevoyage* is explained briefly in the research design section, where examples of DEGs, educational VR games, applications with positive learning outcomes, and inspirational cinematic storytelling works were also mentioned. During the research process, the opinions of scholars and students were asked via an online survey. Their suggestions for designing an educational VR game for cinematic storytelling were also evaluated in the findings section.

Significance of the Study

Although there are some existing or underdevelopment applications for PC, mobile, and VR platforms like Cinedesigner, Tvori, Mindshow, Source Filmmaker, Film Engine, Vpet, Tiltbrush, Oculus Medium, Limitless VR, Modal VR, Animator by Daydream, all of which might be helpful in teaching different aspects of cinematic

Educational Virtual Reality Game Design for Film and Animation, Fig. 1 Labster: equipment price comparison (EdTech Europe 2014 Innovation Showcase: Labster)

storytelling, *Cinevoyage* is probably the first educational VR game design proposal that is purely designed for educational purposes that covers many topics from curriculums of film and animation schools. Thus, there is a need for further research and development to increase the effectiveness of educational games for film and animation.

Cinevoyage combines useful mechanics and design elements from effective examples by introducing the student to a fun and engaging learning environment, which is supported with a narrative storyline, where the student can interact with famous filmmakers from film history. The game design allows the student to learn from filmmakers like Méliès, Welles, Kubrick, Hitchcock, Kurosawa, Fellini, Trier, Cuaron, etc., by visiting them in the virtual filmmaking environments based on the real sets from their works. This might allow the student to experience a simulated face-to-face lecture by one of her/his role models from the history of filmmaking. Thanks to this interaction, the increasing emotional response by the student can boost motivation and strengthen the effectiveness of learning.

One of the main reasons that Cinevoyage is designed as a VR educational game is that it may provide a virtual simulated practice environment for film and animation students. The students can increase their theoretical knowledge and practical skills on certain equipment like professional film cameras, different types of lighting, and additional supportive grip equipment like dollies, cranes, and many more. Like in the example of the gamified educational VR application Labster (Fig. 1), which provides a practicing area in a virtual science lab with simulated versions of very expensive equipment, *Cinevoyage* is also designed with a similar purpose for film and animation schools. With implementing *Cinevoyage* in their curriculum, the educational institutes can reduce the cost of equipment significantly.

Additionally, *Cinevoyage* can simulate different types of filmmaking locations in VR. Depending on the given tasks in the scenario, the students will be able to practice in studios with artificial lights or in exterior locations with natural lights, in day and night conditions or under various weather conditions like rain, wind, and snow.

The recent technological developments created also new debates like whether VR may be the end of cinema as we know it. Although the number of VR video productions is increasing every year, VR still does not seem to threaten the classical film and animation productions as we know it. Nevertheless, these new technologies might introduce new filmmaking methods for the future filmmakers. The democratization of technology allows many independent creative people from around the world to design and develop their own short films, animations, games, and various types of applications. We might witness that virtual filmmaking can be one of the main methods of creating cinematic storytelling works in the future (Morozov 2008). *Cinevoyage* can also be considered as an early example that hints what kind of virtual filmmaking tools can be used by future filmmakers. For this purpose, in addition to

the narrative based system with levels, it is considered to implement a free-to-play area within the game, where the student can act as the director of their own scene, where they can choose the equipment, props, actors, coworkers and the style of the material freely in addition to task-based levels.

The content in *Cinevoyage*, which consists of the equipment, props, characters, virtual locations, and tasks, can be extended depending on the development process and the demand in the long term. The design proposal in this article should be considered as a brief glimpse of what *Cinevoyage* is aimed to become at the end of the continuing iterative design and development process.

Methodologies

This section of the article reviews six different design methodologies for educational games, all of which are listed in chronological order from the oldest to the newest. Their most strong and relevant aspects were analyzed and used as helpful resources during the design process of *Cinevoyage*.

Although the FIDGE-model design methodology was proposed by Akilli and Cagiltay (2005), the strategies offered by the researchers in the pre-analysis, analysis, and development phases were beneficial during the research and design process of *Cinevoyage*. The word FIDGE in the title stands for "Fuzzified Instructional Design Development of Game-like Environment" for learning (p. 7). The researchers emphasize the fuzzy logic principle by citing supporting research about it, which basically refers to nonlinear, dynamic approximate and sometimes irrational reasoning of human beings. This approach allowed the researcher to create a design methodology, which is more dynamic and flexible compared to unrealistic strict methodologies, which can be time consuming (p. 3). The researchers determined these following issues in the pre-analysis section, which "addresses the needs of novice instructional designers" (Akilli and Cagiltay 2005, pp. 9, 15); first the instructional designer should decide on her/his target group; second, the instructional designer must decide on the educational subject depending on her/his experience. In the case of *Cinevoyage* this target group can be considered as film and animation students and the subject can be defined as cinematic storytelling. In the third step the instructional designer should make a literature review to investigate whether the selected educational content is suitable for a GBL application. If supporting evidence is found, then designer should specify the pedagogical objectives of the educational game for the selected target group. After this step, the designer should collect data from experts within these fields by asking their opinions and recommendations via primary research tools like surveys or interviews. This step was followed carefully for *Cinevoyage* too. Some of the answers to certain open-ended questions in the survey can be found in the findings section. The designer is also responsible in analyzing the technical aspects of the game development tools; in the case of *Cinevoyage* this step should include both the software and the hardware side due to the technical requirements of VR headsets with various alternatives. The designer should also analyze existing games to decide which genre, platform, and game elements are most suitable for the targeted educational game. As explained in the following sections *Cinevoyage* is decided to be point and click adventure style, narrative VR game with interactive 3D worlds and characters, which is supported with fantastical elements in harmony with real historical anecdotes. Table 1 gives a summary of the analysis and design and development approaches of the proposed methodology.

Second methodology proposed by Göbel et al. (2009) is based on an educational game project in the field of technology-enhanced learning of geography with the aim of harmonizing different features and objectives of the storytelling, learning, and gaming approaches as seen in Fig. 2. The design methodology of the game *80 Days* is based on several principles. The designers used the storytelling as an instrument for suspenseful knowledge transfer by implicating an emotional immersive dramaturgy. The gaming aspects of the teaching material were intended to create a fun,

Educational Virtual Reality Game Design for Film and Animation, Table 1 Summary of the FIDGE model (Akilli and Cagiltay 2005)

Issue	Its property
Participants	All of actively participating learners and experts
Team	Multidisciplinary, multi-skilled, game-player experience
Environment	Socio-organizational, cultural
Process	Dynamic, non-linear, fuzzy, creative, enriched by games' and simulations' elements (fantasy, challenge, etc.)
Change	Continuous, evaluation-based
Evaluation	Continuous, iterative, formative and summative, fused into each phase
Management	Need for a leader and a well-planned and scheduled time management
Technology	Suitable, compatible
Use	By (novice/expert) instructional designers and educational game designers for game-like learning environments and educational games

Educational Virtual Reality Game Design for Film and Animation, Fig. 2 Technology-enhanced learning (Göbel et al. 2009)

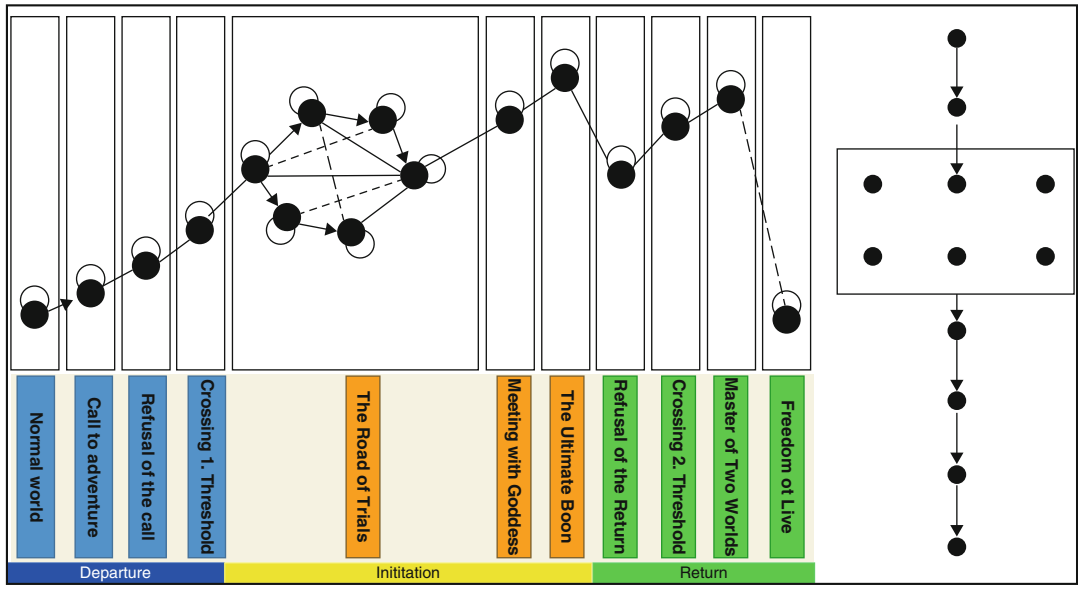
motivational, interactive, and explorative experience. For the learning part, they have emphasized the assessment and learning success by imple menting, motivating, and engaging mechanisms effectively. To prevent a too linear and non-interactive plot-based approach in storytelling, the designers have used the Hero's Journey storytelling model as a template in a flexible way with variations they made in the "The Road of Trials" step for ludological purposes as is seen in Fig. 3 (Göbel et al. 2009). Because of the emphasis on using the Hero's Journey story template in a balanced way, which allows the player freedom to play instead of a boring and too linear story structure, this methodology convinced the researchers and designers of *Cinevoyage* to write the game script in accordance with the same template.

The third methodology study by Marfisi-Schottman et al. (2010) describes the production of a DEGs in seven steps (Fig. 4). For *Cinevoyage* the first three steps are successfully completed. Currently the researchers and designers are working together to evaluate the software solutions for building the mechanics and dynamics of the first play-testable prototype of the game. Once completed, the prototype will be evaluated by scholars according to the GameFlow model (Sweetser and Wyeth 2005) and instructional game design criteria.

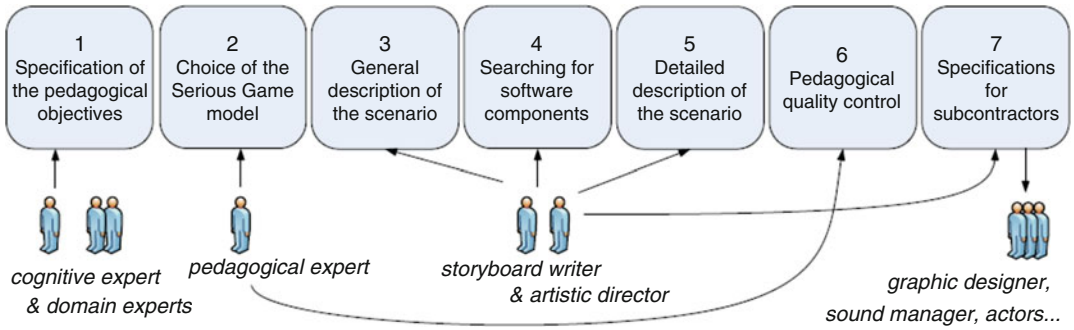
In the fourth study "A New Methodology of Design and Development of Serious Games" Barbosa et al. (2014) propose a new methodology of design and development of educational games, which are enriched with mini-games for having the potential of providing engaging and motivating experiences. This methodology suggests that a main game section with missions and independent tasks like mini games, puzzles, or quizzes serve to transfer knowledge and skill that run in a parallel way without distracting the player too much from the engaging narrative elements (Barbosa et al. 2014, p. 3). In the light of this study, mini-levels are implemented in *Cinevoyage* too (Fig. 5).

The fifth methodology study to design educational games based on interactive screenplays by Prieto et al. (2015) was again emphasizing the importance of creating a detailed scenario in accordance with educational objectives, which will allow the player a fun and emergent learning experience with the support of designed educational game. During the script writing process of *Cinevoyage*, Prieto's methodology functioned as a strong guide (Fig. 6).

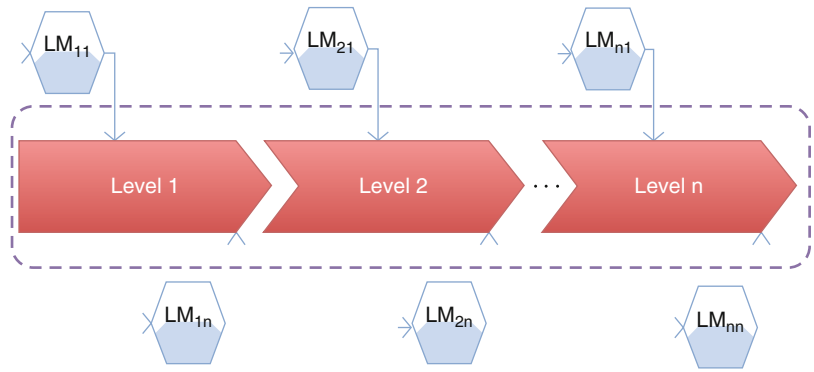
Finally, the dissertation study by Khanana (2016) demonstrates that the old "GameFlow



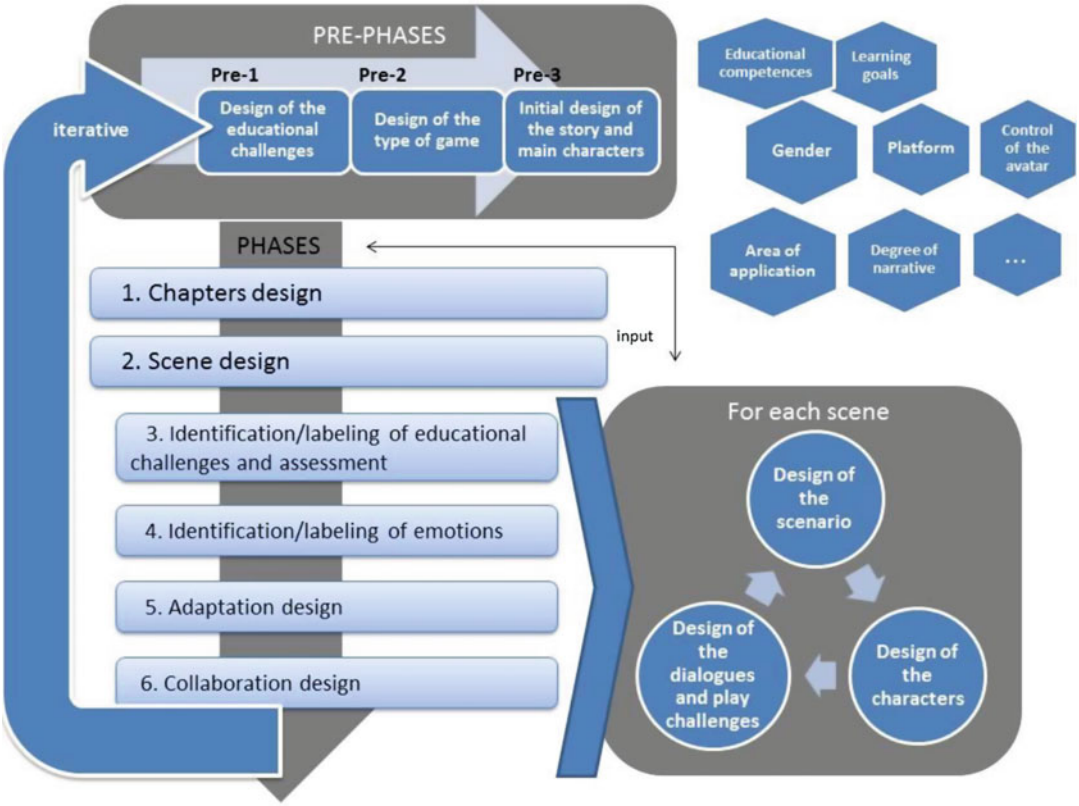
Educational Virtual Reality Game Design for Film and Animation, Fig. 3 Hero's Journey story model (left)/linear and modular story units (right) (Göbel et al. 2009)



Educational Virtual Reality Game Design for Film and Animation, Fig. 4 The seven steps for designing SGs. From tools and methods for efficiently designing serious games (Marfisi-Schottman et al. 2010)



Educational Virtual Reality Game Design for Film and Animation, Fig. 5 Diagram of the methodology; a game with several levels and the learning mechanisms associated to each layer (Barbosa et al. 2013)



Educational Virtual Reality Game Design for Film and Animation, Fig. 6 Methodology based on interactive screenplay (Prieto et al. 2015)

model," which was structured by Sweetser and Wyeth (2005) as a design and evaluation tool for educational games in accordance with the flow theory by Csikszentmihalyi (1990), can still be very effective in the field of educational games. The researcher's main purpose in this study is to propose a simplified, fun design and evaluation methodology for students 7–11 years old. "The gaps of GameFlow model" in this study presents a deep analysis of the eight elements of GameFlow model, which are concentration, challenge, player skills, control, clear goals, feedback, immersion, and social interaction (Khanana 2016, pp. 88–89). Even though *Cinevoyage* is not designed for this young age group the pilot study results by Khanana were instrumental in making the design decisions like the clear goals, good explanations, appropriate challenge levels, nondistractive audiovisual characters, environment and interface, and informative in-game feedback.

Research Design

Gaming Objectives

The objective of the game is to start and complete a journey through the history of cinema, while learning the fundamentals of film and animation making. During the game, the player visits various film sets from different epochs of film history, where s/he interacts with famous filmmakers, who give the player various tasks to proceed further to next levels, where the difficulty but also the reward values increase.

Pedagogical/Educational Objectives

This game is designed as an educational game for film and animation students. Learning occurs by listening, observing, and doing, while the players explore the virtual environments and interact with the characters. The difficulty and the complexity of the knowledge and skills that should be acquired with *Cinevoyage* increase as the player reaches higher levels by completing given tasks successfully.

In *Cinevoyage* the player should be able to reach the following objectives:

To be able to operate the simulated versions of professional cameras, various lighting and grip equipment like dolly, crane, Steadicam, etc., while demonstrating theoretical knowledge on general cinematography

To become more familiar with terms like ISO, shutter speed, aperture, frame per second, depth of field, color temperature, various lenses

To be able to read and understand the following diagrams to complete the tasks:

- Mise-en-scène diagram (showing the movement of the actors)
- Camera diagram (showing the place, angle (s), lens, and movement)
- Lighting diagram (showing the place and type of the equipment)
- Storyboards (showing the framing, shot scales, camera movement)

To be able to work in different filmmaking conditions like in interior and exterior locations with various lighting and weather conditions, which can be both natural or artificial

Victory Conditions

In *Cinevoyage* the player interacts with characters from film history to learn about the task/assignment, which s/he must solve. If the player successfully completes the task, s/he gets immediate feedback from the character and gains the artifact, which enables the player to continue her/his journey to higher levels of the game. As indicated in the "Game Levels" section, the instructor of the educational institute can decide which levels the student should play in relation to their curriculum and learning objectives.

Failure States

If the player cannot succeed in completing a mission, s/he can quit that certain mission and practice with the equipment in a free practice and learning area. The storyline allows to switch to a different mission if the player finds it too difficult. Normally, the player must complete all the tasks to finish the game; however, the instructor of the educational institute can lead their students to play certain levels while skipping some other levels which are more relevant to their learning curriculum.

Another important aspect that needs to be regarded carefully is that the current VR technology can cause health problems like nausea, blurry vision, or headache if played for very long durations (Merhi et al. 2007). This aspect of VR technology is also important to remind the students not to play all levels at once, which might take hours. A typical level of *Cinevoyage* can be passed in 5–20 min. To prevent playtimes longer than 30 min, which can be detrimental to the health of the student, a time limit is also implemented in the design. Accordingly, if the player fails to pass a level in 30 min, s/he can be declared unsuccessful and can only continue after a certain break period.

Game Levels

Research on educational games demonstrates that they are most effective if the educational content is supported with regular lectures (Bonde et al. 2014). Therefore, it is intended to design *Cinevoyage* in such a way that the instructor can choose and lead their students to play certain levels in accordance with their curriculum.

On the other hand, the level design of the game is constructed with references to Hero's Journey story design template. In *Cinevoyage* the player experiences a journey with a guide, which can travel beyond time and space. *Cinevoyage* progresses through several increasingly difficult and complex levels. In each level the player must demonstrate her/his knowledge to perform the given tasks successfully.

If the player successfully completes a level, s/he can travel to the next level. The levels address various learning objectives starting from easy to hard. The player will travel chronologically through levels, which will begin in the early periods of film history around 1900s and will continue till 2017 and beyond. The complete list of levels and the specific educational objectives of each level are briefly summarized in the Tables 2 and 3. Ongoing development phase for a playtestable *Cinevoyage* prototype is going to consist the first five levels. The narrative and visual details of the first five levels are given in the narrative, storyboard, and flowchart sections.

As explained in the methodologies section, the mini-games are also considered as an effective way of knowledge transfer and skill improvement without affecting the game narrative negatively. Therefore, some of the above-mentioned learning objectives will be achieved with the support of mini-games, puzzles, or quizzes.

The Characters

During the gameplay of *Cinevoyage* the player will be able to interact with simulated 3D modeled characters from filmmaking history. In addition to the above listed famous filmmakers, who will both give tasks and instruct the player during the game, there will be additional 3D modeled characters for cast and crew members. As a part of the narrative, the designers decided to use George Méliès as the main mentor of the player, who will be able accompany the player throughout the levels. His character will reflect his abilities as an inventor and magician. His invention *Cinemagica*, which was inspired from actual Méliès short films, functions as a magical inventory box that can keep all kinds of equipment and necessary tools within, will be with the player through all levels.

Game Narrative

As explained in the methodologies section, the main story structure of *Cinevoyage* is based on the Hero's Journey story template, which is claimed to be one of the most occurring story template throughout the human history. As the methodology examples show, Hero's journey is used efficiently in many educational games by allowing the players to go through an emotional journey, while increasing their knowledge and improving their skills. The following storyboard and flowchart sections give a glimpse of the game script for the first five levels.

Storyboard

The storyboard template (Fig. 8), which is used to visualize the first five levels of *Cinevoyage* (Figs. 9 and 10), is a combination of two different templates, which are created by VR developers McCurley (2016) and Leitch (2017), both are based on Mike Alger's presentation with the title

Educational Virtual Reality Game Design for Film and Animation, Table 2 Levels and learning objectives of *Cinevoyage* (0–5)

Level	Movie	Scene	Filmmaker	Learning Objectives
0_Introduction	–	Introduction: Cinemagica	George Méliès	Tutorial for basic mechanics to move, select & interact
1_The Bridge	Photo shooting of the horse (1878)	Movement	Eadweard Muybridge	Fundamentals of photography; exposure, iso, aperture, shutter speed
2_Action!	Arrival of Train at La Ciotat (1895)	Arrival	Lumière Brothers	Shot scales, exposure, iso, aperture
3_Crosscut	The Great Train Robbery (1903)	Train station	Edwin S. Porter	Parallel editing, special effects
4_Montage	Kuleshov Experiment (1919)	a + b1 = x a + b2 = y a + b3 = z	Lev Kuleshov	Montage theory
5_Wake Up	Dr. Caligari (1920)	Cesare's Awakening	Robert Wiene	Lighting, framing

Educational Virtual Reality Game Design for Film and Animation, Table 3 Levels and learning objectives of *Cinevoyage* (6–20)

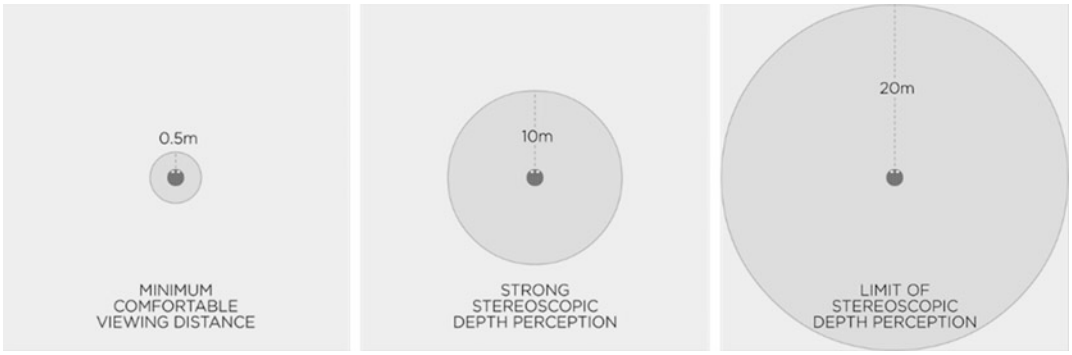
Level	Movie	Scene	Filmmaker	Learning objectives
6_Retrofuturo	Metropolis (1927)	City miniature	Fritz Lang	Studio shooting, lighting, special effects
7_The Prodigy	Citizen Kane: (1941)	Childhood scene	Orson Welles	Storyboard reading, frame composition, blocking
8_Eastlight	Seven Samurai (1954)	Flag scene	Akira Kurosawa	Frame composition, camera movement
9_The Master	Vertigo (1958)	Vertigo effect	Alfred Hitchcock	Focal length, camera movement
10_Dreamman	8 1/2: (1963)	Asa Nisi Masa	Federico Fellini	Black & white lighting
11_End of Beginning	2001: A Space Odyssey (1968)	Final room scene	Stanley Kubrick	Shot/reverse shot, lighting, colors
12_Houston, we have a Problem!	Barry Lyndon (1975)	Interior, candlelight	Stanley Kubrick	Zoom, depth of field, lighting, lens aperture
13_Depth	Stalker (1979)	Tunnel scene	Andrei Tarkovsky	Composition, depth of field, camera movement
14_Track the Fall	Wings of Desire (1987)	Fall of an angel	Wim Wenders	Shot scales, tracking shot
15_The Bridge	Matrix (1999)	Bullet time effect	Watchowskis	Green screen, special effects, bullet time
16_Location or Not	Dogville (2003)	Introduction	Lars von Trier	*Mise-en-scène,* camera movement
17_Stopmotion	Corpse Bride (2005)	Meeting Emily	Tim Burton	Stop motion, frame composition, lighting
18_Plansequence	Children of Men (2006)	Car scene	Alfanso Cuaron	Advanced plan sequence, scene blocking, shot scales
19_Back to Station	Hugo (2011)	Train crash	Martin Scorsese	Special effects with green screen
20_Resolution	The Revenant (2016)	Church	Alejandro G. Iñárritu	Composition, Imax cameras, crowded scene experience, snowy weather

"VR Interface Design Previsualisation Methods" (2015). As shown in Fig. 7 designing for VR requires to pay attention to certain details like the distances between the objects and the player to provide a comfortable VR experience for the users, which can be planned during the storyboarding process.

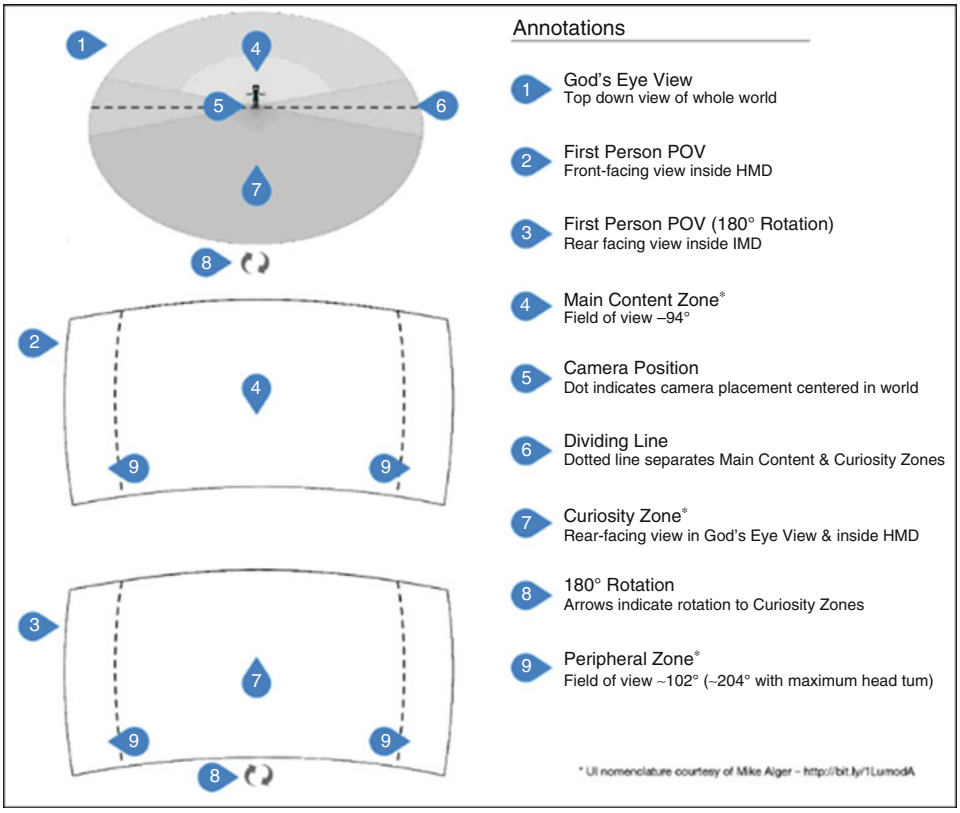
The storyboard combines the written information from the narrative script of the game with the visual information that represents a basic version of how the game world, the characters, and the objects should look and how the player is going to interact with them. The storyboard of the first five levels of *Cinevoyage* shown in Figs. 9 and 11 gives the information about where in the virtual world the first-person player will be located; about the famous characters the player is going to meet and interact; about the references to actual movies from film history; about the objects that the player will acquire and the actions that occur when interacting with them; about the vehicles like the Cinetrain, with which the player is going to travel within the game; about the user interface like the camera display; and about the tasks that needs to be fulfilled to pass a certain level.

Flowchart

The flowchart is another important part of a Game Design Document, which functions as a communication platform among the game designers, programmers, and audio-visual asset creators. The flowchart for the first five levels of *Cinevoyage*

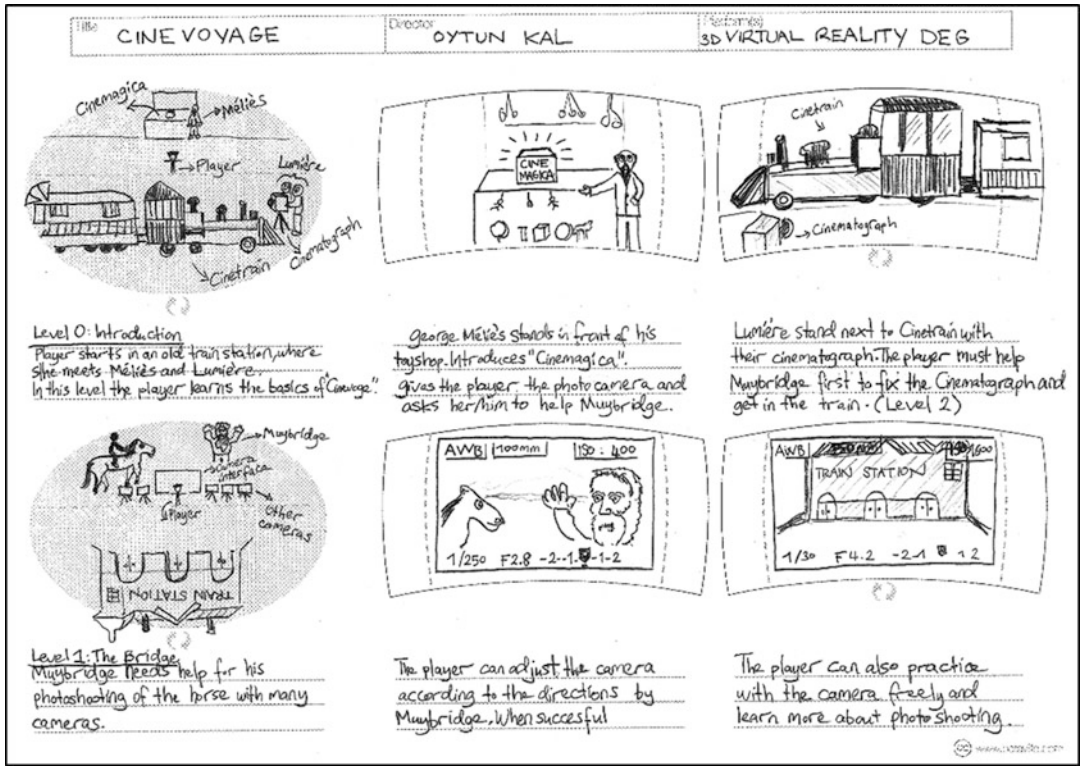


Educational Virtual Reality Game Design for Film and Animation, Fig. 7 VR viewing distance (virtualrealitypop.com)


Annotations
1 God's Eye View
Top down view of whole world
2 First Person POV
Front-facing view inside HMD
3 First Person POV (180° Rotation)
Rear facing view inside IMD
4 Main Content Zone*
Field of view ~94°
5 Camera Position
Dot indicates camera placement centered in world
6 Dividing Line
Dotted line separates Main Content & Curiosity Zones
7 Curiosity Zone*
Rear-facing view in God's Eye View & inside HMD
8 180° Rotation
Arrows indicate rotation to Curiosity Zones
9 Peripheral Zone*
Field of view ~102° (~204° with maximum head tum)
* UI nomenclature courtesy of Mike Alger - http://bit.ly/1LumodA

Educational Virtual Reality Game Design for Film and Animation, Fig. 8 Annotations for VR storyboard template (virtualrealitypop.com & medium.cinematicvr.org)

in Fig. 11 depicts what the player will be experiencing throughout the gameplay. From this flowchart one can acquire information about the beginning process of the game; about the user interface that will guide the player to select the relevant menus like the settings, lecture videos, or the new game menu; about the place and the number of cut scenes; about the characters the


CINE VOYAGE
OYTUN KAL
3D VIRTUAL REALITY DEG
Cinemagica
Méliès
Player
Lumière
Cinetrain
Cinematograph
CINE MAGIKA
Level 0: Introduction
Player starts in an old train station, where she meets Méliès and Lumière.
In this level the player learns the basics of Cinevoge.
George Méliès stands in front of his toyshop. Introduces "Cinemagica".
gives the player the photo camera and asks her/him to help Muybridge.
Lumière stand next to Cinetrain with their cinematograph. The player must help Muybridge first to fix the Cinematograph and get in the train. (Level 2)
Muybridge
Player
Other cameras
AWB
100mm
ISO: 400
1/250 F2.8
TRAIN STATION
1/30 F4.2
Level 1: The Bridge
Muybridge needs help for his photoshooting of the horse with many cameras.
The player can adjust the camera according to the directions by Muybridge. When succesful
The player can also practice with the camera freely and learn more about photo shooting.

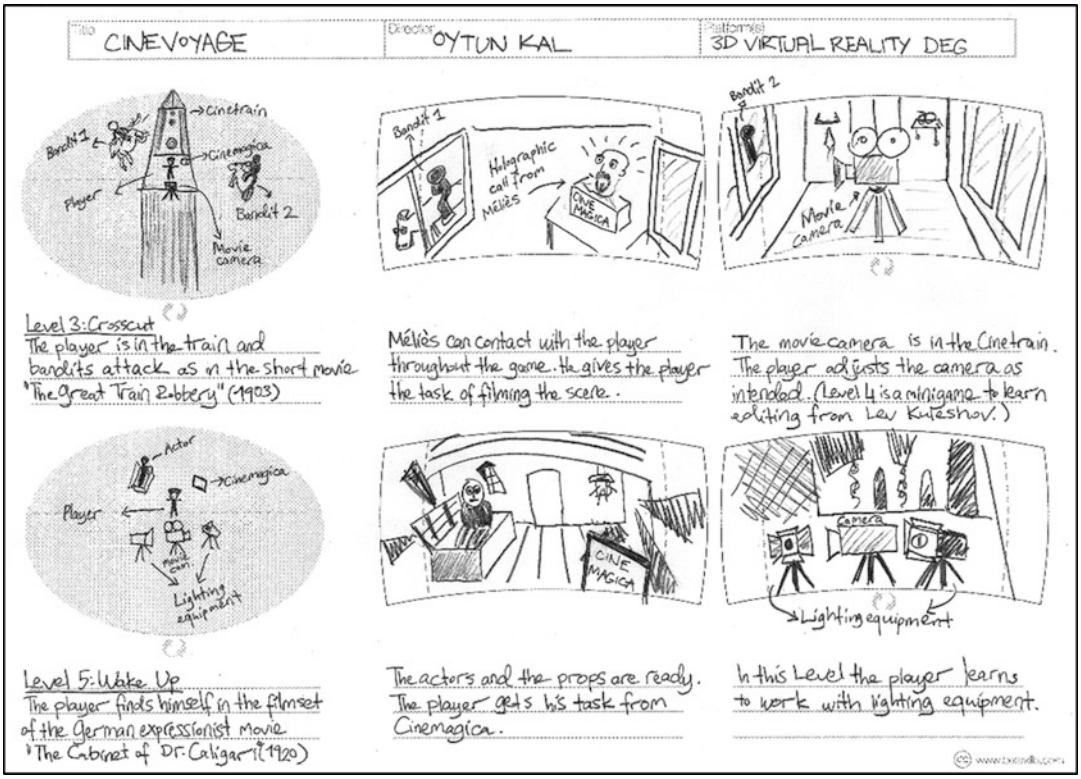
Educational Virtual Reality Game Design for Film and Animation, Fig. 9 *Cinevoyage* storyboard (levels 0–2)

player is going to meet and interact within the game; about the given tasks and the free play modes; about the game objects that should be acquired and what to do with them; about the number and passing conditions of the levels; and about the main game mechanics like to teleport from one place to another.

Findings

The deep literature review for this study enabled the designers to determine which elements of which design methodologies will be used while designing *Cinevoyage*. After a collaborative work of game designers and instructional designers, the finished Game Design Document of *Cinevoyage* and an online survey was shared with a selected group of people to gather suggestions and recommendations on the general design of the game. Thirty-four out of 92 people, who responded the online survey, claimed that they have experience as an instructor or teacher in film making, video production, photography, and similar branches. Some response examples by these people to the open-ended question "In which ways could you benefit from the educational VR game *Cinevoyage* in your lectures?" can be seen in Table 4.

As is seen Table 4 there are many participants who emphasized the importance of gaining practical experience within the simulated filmmaking environment. Even the participants, who had little or no experience with VR environments can easily imagine how it would benefit the students, when they can play with virtual filmmaking equipment without the fear of making mistakes. Considering the fact many educational institutes cannot afford the professional level film equipment due to the high costs and security risks *Cinevoyage* is

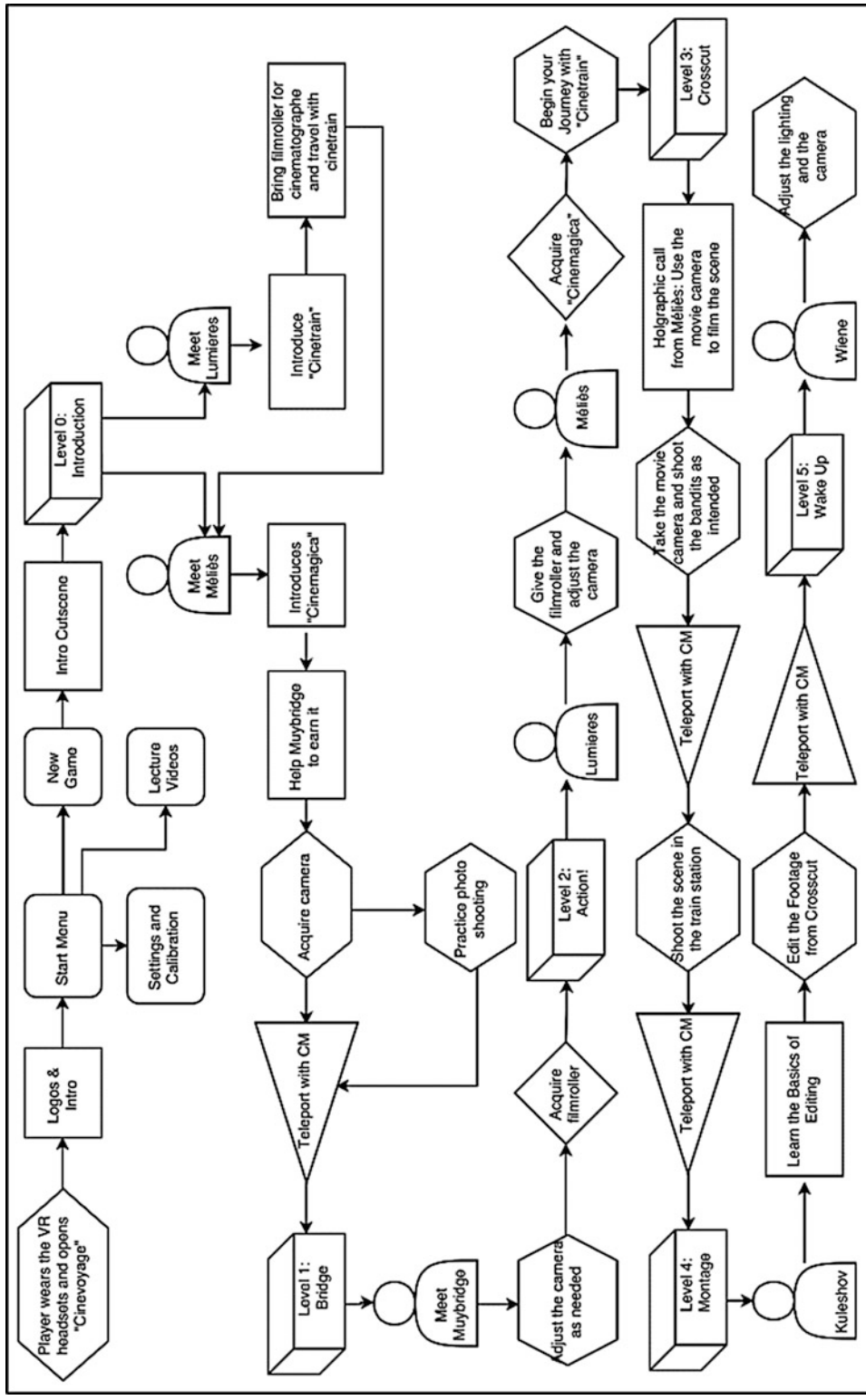

CINEVOYAGE
OYTUN KAL
3D VIRTUAL REALITY DEG
Cinetrain
Bandit 1
Cinemagica
Player
Bandit 2
Movie camera
Holographic call from MELIES
CINE MAGICA
Movie camera
Level 3: Crosscut
The player is in the train and bandits attack as in the short movie "The Great Train Robbery" (1903)
Méliès can contact with the player throughout the game. He gives the player the task of filming the scene.
The movie-camera is in the Cinetrain. The player adjusts the camera as intended. (Level 4 is a minigame to learn editing from Lev Kuleshov.)
Actor
Cinemagica
Player
Lighting equipment
CINE MAGICA
Camera
Lighting equipment
Level 5: Wake Up
The player finds himself in the filmset of the German expressionist movie "The Cabinet of Dr. Caligari" (1920)
The actors and the props are ready. The player gets his task from Cinemagica.
In this Level the player learns to work with lighting equipment.

Educational Virtual Reality Game Design for Film and Animation, Fig. 10 *Cinevoyage* storyboard (levels 3–5)

designed with the purpose of enabling the students to work with virtual filmmaking equipment (Sheffield 2001). Additionally, *Cinevoyage* aims to simulate the social aspects of filmmaking too like the interaction with the director or other cast and crew members on a film set, which was considered as an important factor within the survey results (Table 4).

Conclusion and Discussion

According to the study performed by Connolly et al. (2012) the most frequently occurring outcome with educational games was knowledge acquisition and content understanding. The methods of measuring the outcomes of the educational games differed from study to study. The most popular study design for collecting empirical data on knowledge acquisition, motor skills, perceptual and cognitive skills, and physiological outcomes is quasi-experiment, followed by randomized control trials (RCT), surveys, and qualitative designs. On the other hand, to study the affective, motivational, and social outcomes of the games, researchers used mostly surveys even though these were typically to secondary interest (Connolly et al. 2012). To measure the affective and motivational outcomes of the DEGs some researchers used questionnaires. Jennett et al. (2008) used a subjective questionnaire to distinguish immersiveness levels of games based on cognitive involvement, emotional involvement, real-world dissociation, challenge, control, and eye movements. Fu, Su, and Yu's study (2009) found that Sweetser and Wyeth's GameFlow model (2005) can be used effectively in evaluating the motivational features of educational games.



Educational Virtual Reality Game Design for Film and Animation, Fig. 11 Flowchart for *Cinevoyage* (levels 0–5)

Educational Virtual Reality Game Design for Film and Animation, Table 4 Response examples to the survey question "In which ways could you benefit from an educational VR game in your lectures?"

"It could function as a simulation game. If the class that is being taught needs practical skills, it could be used to practice that skill and improve on it without worrying about failure. It would allow the user to learn the skill in a safe, but realistic environment."
"By creating a simulated interactive environment, you can adjust light, distance, lens, camera height, angle etc. *in comparison with various options."*
"Cinevoyage could function as a simulation game. If the class that is being taught needs practical skills, it could be used to practice that skill and improve on it without worrying about failure. It would allow the user to learn the skill in a safe, but realistic environment."
"By creating an interactive environment simulation with this VR game, students can learn quickly to adjust elements like the time, light, distance and lens angle, camera height, angle etc. *in combination with each other."*
"Learning camera and lens, editing, light, and even script writing, can become faster and more fun with the help of a VR game like "Cinevoyage". The burden of collecting visual material for the lecturer would be less with the support of these games. In an interactive virtual film studio, the student can feel like a real cameraman, who takes her/his directions from the director, which would allow her/him to experience theory and the practice at the same time instead of a passive listening experience"

The first working prototype of *Cinevoyage* is planned to be tested within 2018 in some educational institutes. The research and design team is planning to make both similar quasi-experiments with control groups to compare the learning outcomes of cinematic storytelling lectures with the support of *Cinevoyage* versus classical lecture methods. Additionally, the game will be evaluated both by instructors and students according to evaluation surveys and questionnaires like Game Features Test, Instructional Game Survey, and GameFlow model to collect secondary data on motivational and social outcomes, levels of immersion, and engagement of the students during gameplay (Samur 2012).

Cinevoyage is currently under development with a team of script writers, game developers, 3D and instructional designers for room-scale VR platforms with high-end PC support like Oculus Rift, HTC Vive. Additionally, a smaller mobile VR version for platforms like Samsung Gear VR and Google Daydream are in consideration, which are planned for quick prototyping sessions. As can be seen within this article *Cinevoyage* has a very wide scope and it can be expanded as the demand occurs. Currently, funding opportunities for a sustainable design and development process of *Cinevoyage* are being investigated by the researchers too.

Moreover, as the study by Zhang and Zhao (2017) exemplifies successfully that AR is also very promising to support education. Therefore, the design team of *Cinevoyage* is also experimenting with technologies like ARkit for Apple devices and ARCore for Android smartphones and how they can be used for cinematic storytelling education too.

Cross-References

- ▶ Augmented Learning Experience for School Education
- ▶ Gamification and Serious Games
- ▶ Interactive Augmented Reality to Support Education

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Edutainment

▶ Domain-Specific Choices Affecting Design Effort in Gamification
▶ Public Health Education via Computer Games

EEG as an Input for Virtual Reality

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Synonyms

BCI, brain–computer interface; EEG, electroencephalography; Virtual reality

Definitions

Brain-computer interfaces (BCI) use electrophysiological measures of brain functions to send inputs to a computer from a new non-muscular channel (Wolpaw et al. 2002). In this entry, the use of electroencephalography (EEG) is introduced as a BCI input for virtual reality (VR). A VR mini-game is developed to showcase the use of EEG as an input in VR. With EEG, using the predefined brainwave patterns that are defined via EEG as a set of commands, users can interact with their environments in VR dynamically, through the changes in their emotional mood and concentration. This does not only introduce an alternative input for VR, in which the physical body's integration is somewhat restricted due to the technological limitations, but also enables authentic digital realm experiences which would be impossible in the physical world.

Introduction

Ability to move objects with the mind has always been an intriguing subject for humans. The idea of being able to interact with our environment without direct physical contact has been at the center of the works of fiction as well. The concept of *Force* in Star Wars film series is an excellent example of it, which helps certain characters who can use it to perform telekinesis (Bouzereau 1997). Despite that any parapsychological effort has failed to show any credible real-world evidence for the practice of telekinesis, which is based on illusion, science has finally developed new brain–computer interface (BCI) technologies that allow humans to interact with their environment solely concentrating with their minds. Electroencephalography (EEG) is one of these BCI technologies. EEG is monitoring the electrical activity of the brain, measuring voltage fluctuations from electrodes placed on the scalp (Fisch and Spehlmann 1999). EEG has been studied widely as a part of neurology, psychology, and marketing studies, and it is commonly used in the industry fields like education, rehabilitation, entertainment, and user experience design (Wolpaw et al. 2002; Finkelstein et al. 2010; Mulert and Lemieux 2009; Friedman 2015). With the recent developments in wearable technologies and EEG headsets, they became more affordable and available for casual end users. Therefore, EEG is increasingly used as a swift and unique BCI input, which enables user interaction via brain waves or "thoughts" in virtual environments (Li et al. 2017).

VR and EEG

Virtual reality is a different realm where all the experience takes place beyond the physical realm. Thanks to the current persuasively photorealistic CGI technologies, increasing processing speed, improved refresh rate on displays, and affordability of the user hardware, virtual reality has been a popular subject once again (Jerald 2015). Every

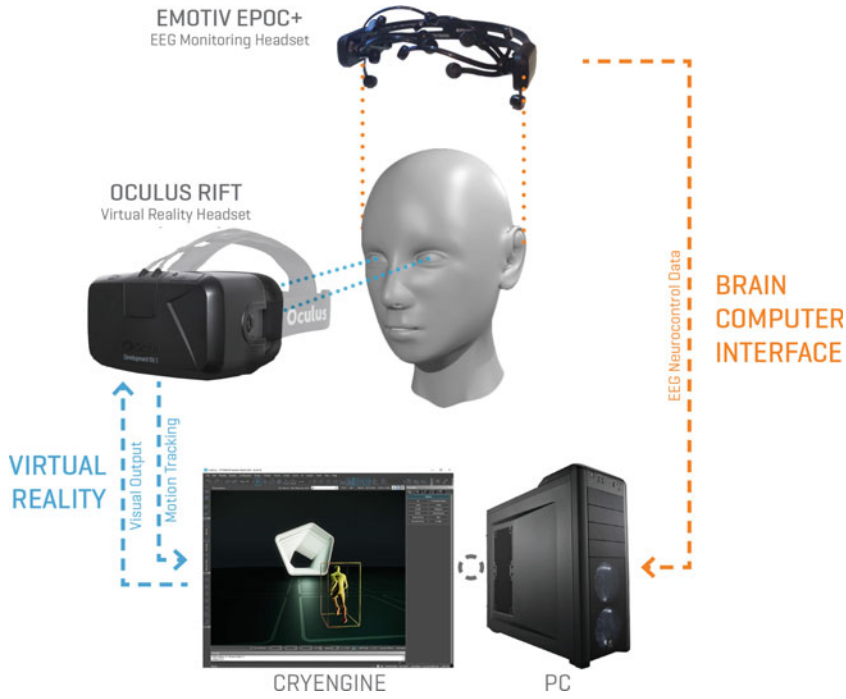
day more and more VR headsets are being sold, and more VR content is being developed. Therefore, VR is far beyond being an experimental technology but becoming an essential part of how we interact with the digital realm. Several universities and laboratories have used EEG as a control input for virtual environments and video games successfully (Lecuyer et al. 2008). Using EEG in VR makes the experience even more immersive.

Transferring the user's inputs and movements to VR as comprehensive as possible ensures an immersive experience. These inputs are mostly within the possibilities of what humans already have in the physical world: movements, controllers, haptics, eye tracking, and vocal commands, to name a few. This gap between physical and virtual adds to the ambiguous manifold of reality and virtual realities. This critical duality also leads to new opportunities, which weren't available before the digitally manufactured realities. Virtual does not necessarily need to be an epigone of the reality. As Baudrillard put it, simulation creates its own hyperreality, beyond its referential reality (Baudrillard 1999). By using the authentic new opportunities of this hyperreality, it is possible to represent the human body in the virtual space in novel ways that it cannot be represented in the physical space and enable novel interactions that are not possible in the physical reality. It also delivers more enhanced inputs faster into the virtual environments (Li et al. 2017). While bodily existence in VR is a critical one, using brain waves as an interface between the brain and the virtual space will enable manipulation, interpretation, and recreation of that space only using the brain itself.

In the project that is mentioned in this article, EEG was used to create a dynamic interaction via neural controls for a VR video game experience. The players can dynamically interact with the VR environment with the changes in their emotions and mental concentration.

Method

This project makes use of two technologies: VR and EEG. The player experiences the VR video



EEG as an Input for Virtual Reality, Fig. 1 Brain-Computer Interface (EEG) and Virtual Reality pipeline of the project

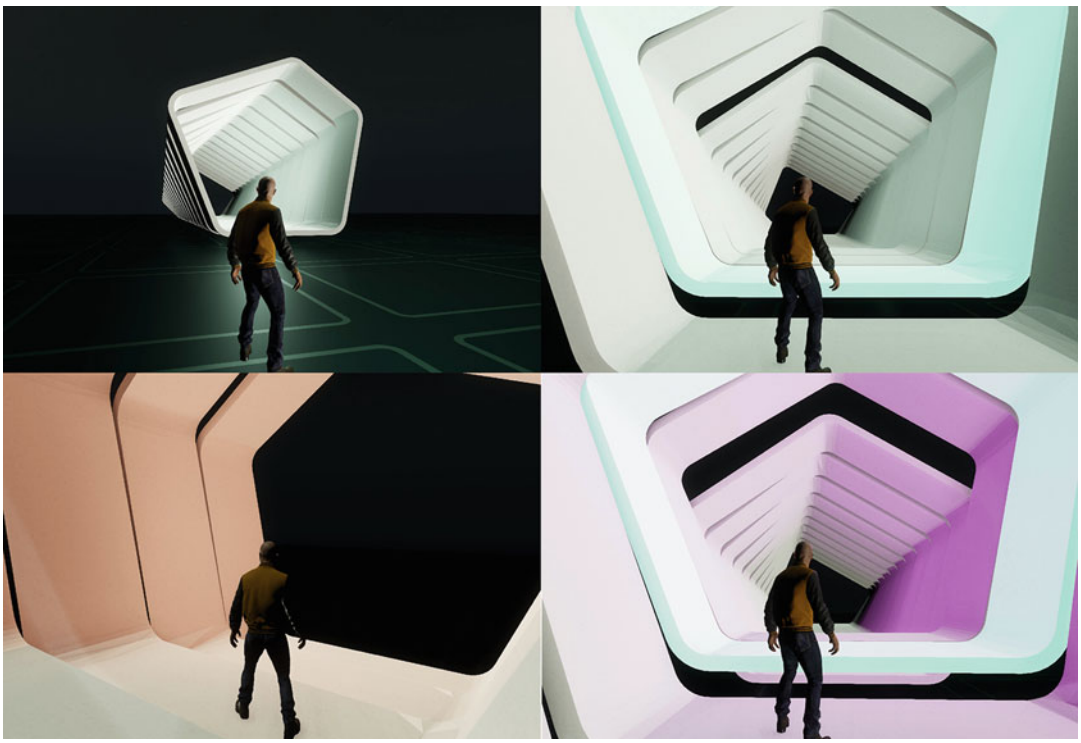
game created in CRYENGINE via Oculus Rift VR headset. The core mechanic of the designed gameplay is simple; the player walks through a segmented tunnel, trying to elevate each segment to form a flight of stairs to reach a higher platform. Meanwhile, the interior lighting of the tunnel changes based on the player's emotions (Fig. 1).

Emotiv EPOC+ EEG headset monitors the player's brain activities and digitizes it as a computer input. Emotiv's dedicated software *EPOC Control Panel* enables certain neural patterns, which the player needs to define it beforehand, to be read as an input for the VR video game. In this project, the players define EEG commands such as push/pull and resize objects in EPOC Control Panel. As seen in Fig. 2, these commands are used as controller inputs by CRYENGINE. *EPOC Control Panel* also streams the excitement, engagement, and meditation levels of the player to CRYENGINE, which is converted into an RGB color for the environmental lighting in the VR game.

In a previous study, users wearing Emotiv EEG headset were able to drive an automobile with EEG commands (Göhring et al. 2013). Therefore, the precision of EEG is considered to be well enough as a controller input for the VR game.

Results and Conclusion

Using EEG as a brain–computer interface for VR provides a new range of unique possibilities and interactions, which would be impossible in the physical world. Making a user move an object with EEG in the physical world would require a lot more effort than moving some object in a video game in VR. Also, wearing EEG headsets is not very fashionable yet, but it is less bothersome when the user is already tethered in



EEG as an Input for Virtual Reality, Fig. 2 The players elevate each segment by concentrating on the push/pull commands they have defined

VR. Considering the existing bodily integration and movement limitations of virtual reality technologies, figuratively connecting the brain directly to the computer by the use of EEG as an input for VR looks very promising for the future applications.

Cross-References

- ▶ Biosensing in Interactive Art: A User-Centered Taxonomy
- ▶ Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface
- ▶ Emotion-Based 3D CG Character Behaviors
- ▶ Foundations of Interaction in the Virtual Reality Medium
- ▶ History of Virtual Reality
- ▶ Locomotion in Virtual Reality Video Games
- ▶ Spatial Perception in Virtual Environments
- ▶ Virtual Reality Game Engines

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EEG Signal

- ▶ Brain Signals as a New Biometric Authentication Method Using Brain-Computer Interface
- ▶ Color Detection Using Brain Computer Interface

EEG, Electroencephalography

- ▶ EEG as an Input for Virtual Reality

Electronic Sports

- ▶ Diversity in Gaming and the Metaverse
- ▶ Online Gaming Industry Evolution, Monetization, and Prospects

Embodied Agent - Autonomous Digital Character

- ▶ Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality

Embodiment

▶ Gamification and Social Robots in Education

Embodiment in Digital Games

▶ Player-Avatar Link: Interdisciplinary Embodiment Perspectives

Emotion Detection

▶ Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications

Emotion in Games

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Synonyms

DLC

Definition

Emotion in games – a feeling such as happiness, love, fear, anger, or hatred while a person is playing a computer game.

DLC – downloadable content, often called DLC, is extra content made for a game after release. It can be given out freely or monetized.

Introduction

Emotion is how we feel and how connected we get to someone or something. In life we cry over the ones we have lost or if we are mad we will be angry at life or at someone. Believe it or not, some people who play video games can get emotional on a character's death or dying so much that they want to break the game controller. (Isbister, 2016)

Character growth is what most players like to see in an intense story-driven game. Some examples of games that show emotion well are *Halo, Mass Effect, Red Dead Redemption, Call of Duty, and Gears of War.* These games present great character growth but they also let their favorite characters die. For example, Dom, in *Gears of War*, is the brother in arms who dies in the third game, sacrificing himself to save his friends and to be with his family. In *Call of Duty*, many memorable likable characters die, including Soap, Ghost, Sandman, Harper, and Mason. In *Mass Effect*, we can build our own character from body and facial features, and transfer them to other mass effect games so we can continue the adventure. However, the character ends up dying at the end of the third game, causing trauma for some players.

Here are some examples of emotion in games: (Freeman, 2004; Yannakakis & Paiva, 2014)

Emotion: Fear.

A player is playing a game and hears sounds that cannot be explained, shadows in the distance, or have a restrictive camera view.

Emotion: Joy.

A player gets a gun or armor piece that is extremely valuable as a reward for completing a difficult trial; they are probably going to be filled with joy.

Emotion: Panic.

Games can induce panic in ways that are tied to story in gameplay. The second chapter of *Super Paper Mario* has the player exploring a mansion for Merlee, an important character. After a few mishaps while exploring the estate, including getting thrown in a dungeon by Merlee's assistant, Mario and company search the basement to find an imposter Merlee. While some players could assume from context clues that Merlee's assistant

was the imposter, players could not predict that the assistant, who calls herself Mimi, would reveal her true form by having her head spin around her neck and sprouting spider legs. From here, Mimi chases Mario throughout the basement until he can find the real Merlee. Despite having a creepy appearance, Mimi is also threatening: She is invincible, can shoot projectiles, and can follow players through doors. This scenario changes a platformer where a character can take their time into a situation where players need to think fast to solve puzzles to get to the end of a maze.

Emotion: Frustration.

Some games are designed to make the player frustrated with difficult challenges. Some players play for the clout of being able to make it through a difficult level.

Emotion: Sadness.

A game that does this well is *Destiny 2* with its DLC, *Forsaken*. In the base campaign, the player gets the feeling of hopelessness. The central hub that was enjoyed in the main game is suddenly under fire and can no longer be accessed, aiming to make the player feel uncomfortable.

Emotion: Vengeance.

Vengeance is not always so predictable. In Forsaken, a main character from the Vanguard, Cayde 6, dies by the hands of Uldren Sov. The goal from thereon out is to kill Uldren Sov by hunting him down the entire campaign. The player does get a feel for vengeance but the hole that Cayde 6 has left for the player will never be repaired.

Emotion Driven by Audio and Music.

The emotional impact of audio and music cannot be understated. (Williams & Lee, 2018) Combining images with audio enhances the impact of a multimodal experience during gameplay. Unlike traditional composition such as film music, game music mirrors the nonlinear narrative of gameplay. Player-dependent actions can change the narrative and thus the emotional characteristics required in the soundtrack. Video games uses various techniques such as algorithmic composition, automated emotion matching from biosensors, motion captures, emotionally targeted speech synthesis and signal processing, and automated repurposing of existing music matching the expected emotion of the players.

Cross-References

▶ Emotion-Based 3D CG Character Behaviors

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Emotional Congruence in Video Game Audio

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Synonyms

Affect; Music

Definition

Video game audio is more challenging in many regards than traditional linear soundtracking. Soundtracking can enhance the emotional impact of gameplay, but in order to preserve immersion, it is important to have an understanding of the mechanisms at work when listeners respond to audio emotionally.

Introduction

Video game soundtracking presents a number of unique challenges in contrast to traditional linear soundtracking (e.g., in television or film). Many solutions are in use to address the most common problem: dynamic soundtrack creation in response to gameplay action, but these often approach the problem from the point of view of, for example, procedural audio techniques (Collins 2009). One of the major reasons to include soundtracking is to enhance the emotional response of the player, for example, to accentuate danger, success, failure, and other elements of gameplay (Berndt 2011). Depending on the type of game, there may be established musical grammars to convey such things, and thus emotional congruence is vitally important in maintaining player immersion (Arsenault 2005). Defining what we mean by "emotion" is important here, as perceptual science often refers to a number of synonymous terms (including mood and affect). These are sometimes distinguished between according to the length and specifics of the feeling, with mood being longer lived, for example (Williams et al. 2014). If a player is in danger, do they feel threatened, excited, afraid, or angry? Are any of these terms quantifiable (is there a medium level of fear that might be increased as the level of danger in the game increases?) and are they distinct and in a linear relationship to one another (if fear increases, will excitement also increase?)? These are difficult questions to answer but of vital importance for the game sound designer if successful emotionally congruent soundtracking is to be achieved. For our purposes we will consider terms including affect, mood, and emotion as being interchangeable, and rather than referring to affective states or moods, we will refer simply to emotion or emotional responses.

How Is Emotion in Music Measured?

There are established methods for evaluating emotional responses in traditional psychology and cognitive sciences (Schubert 1999). These can be, and have been, adapted to the evaluation of emotional responses to music. A popular model is the two-dimensional (or circumplex) model of affect (Russell 1980). This plots positivity (valence) on a horizontal axis and activation strength (or arousal) on the vertical axis. Thus, a player state with high valence and low arousal might be described as calm, peaceful, or simply happy. This approach has the advantage of being able to quantify the emotional response – we can have a sliding scale for both axes and perhaps a particular emotional coordinate for a player at a given point in the narrative of the game. This approach also facilitates some direct mapping to a given soundtrack which matches the player state. However, this type of model is problematic. For example, let us consider a state which is very negative and also very active (low valence and high arousal). How might a player in such a condition be described – afraid? Or angry? Both are very active, negative states, but both are quite different types of emotional response. So three-dimensional models of emotion have also been proposed, for example, including dominance as a third axis (in which case, *afraid* might be a passive response, at one end of the scale in the third axis, and *angry* would be the dominant response at the opposite end of the same scale) (Mehrabian 1996). This three-dimensional model and models like it have also come under criticism when adapted to use with musical stimuli, and multidimensional, music-specific models have recently been used (Scherer 1995).

Challenges and Future Technology

One of the most important issues when considering emotional congruence in video game soundtracking is the distinction between an emotion which the music *communicates* and an emotion which the player actually *feels* (Gabrielsson 2002). Imagine that the player is in a part of the narrative which requires generically happy sounding music. The tune which is selected by the audio engine might resemble circus music, but in this particular case, the player has a phobia of the circus and in particular of clowns. The music may then create the opposite of the intended

emotional state in the player. Similarly, there is a growing body of evidence which suggests that when sad music is played to a listener who are in a similar emotional state, the net effect can actually be that the listener's emotional response is positive, due to an emotional mirroring effect which releases some neurosympathetic responses (Molnar-Szakacs and Overy 2006). There is some research suggesting that music has the power to be perceived as a sympathetic listener and to make people in negative emotional states feel "listened to." Therefore, giving generically sad music to the player at a particular point in the narrative might also be inappropriate. Beyond this, almost everyone has slightly different tastes in music, including preferences for certain genres, performers, and even specific songs (Kreutz et al. 2008). These individual differences are very challenging for the game audio designer to account for, but the greatest challenge remains that of adaptability to nonlinear narrative changes (changes under the control of the player or other game agents). Early solutions such as looping material can become repetitive and ultimately break player immersion. Branching strategies, wherein different music cues are multiplexed at narrative breakpoints, can drastically increase the compositional complexity required in the audio design strategy (Lipscomb and Zehnder 2004). An alternative might be to apply procedural audio techniques, which have been used with varying degrees of success in game sound effect sequencing and design. However, for music tasks, the computational cost involved in procedural generation can be large – for example, if long sequences of pre-rendered audio are required for particular narrative sequences with various nonlinear properties, in response to gameplay and intended emotional state. Such solutions can also require a great deal of compositional complexity (with only limited savings in this regard over branching strategies) but have been used successfully in some instances, for example, LucasArts *iMuse* system (Strank 2013) which was a dynamic music streaming system which initially used MIDI files with varying degrees of transformation to imply characters and emotional states. This system was used to accompany role-playing games (including the *Indiana Jones* series and, perhaps most famously, the *Monkey Island* series of games). iMuse implemented two now commonplace solutions, horizontal re-sequencing and vertical re-orchestration, both of which were readily implementable due to the use of MIDI orchestration as a structural representation of the music soundtrack, rather than a definitive (i.e., recorded and rendered) digital audio file.

In the future, we might see an optimized solution, combining machine learning approaches to composition with an individual's own selection of music or the use of biophysiological measures of emotion to manipulate a soundtrack to best maximize the intended, induced emotional response in an individual gamer on a case-by-case basis. These solutions sound far-fetched at the time of writing, but due to the increase in wearable biosensing technology, and the ever-decreasing cost of more complicated associated technology (facial recognition, electroencephalography, galvanic skin response), such technology may well become commercially viable in the world of game audio soon.

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Emotional Contagion

▶ Simulation of Emotional Crowd and Applications

Emotional Intelligence

▶ Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science

Emotion-Based 3D CG Character Behaviors

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Synonyms

Affective computing; Intelligent argent; Intelligent user interface; Intelligent virtual environment; Human-computer interaction

Definition

Emotion-based 3D CG character behaviors are the various actions of intelligent agents with emotions in virtual space. This article especially focuses on the intelligent agents communicating with a human, i.e., an agent as an intelligent user interface with abilities to understand human's emotions. This topic contains diversified research fields: *Intelligent Agent*, *Intelligent Virtual Environment*, and *Affective Computing*.

Introduction

Nowadays, the user interface connecting a human to a computer has come to play a more important role in our daily life. Since the user interface takes multimodal styles, such as voice input/output interface and haptic feedback interface, many researches about *Human Computer Interaction* (HCI) (Wong and Horace 2008) have been actively made. Especially, *Intelligent User Interface* (IUI) (Sullivan and Tyler 1991) which can sophisticatedly interact with a human by using *Artificial Intelligence* (AI) technologies or *Computational Intelligence* (CI) technologies has a role to promote human-computer communications. IUI with an ability to understand human's emotions enables to make their relationships more closely and friendly. On the other hand, the researches of *Intelligent Agent* in a virtual environment also have developed with AI and *Artificial Life* (AL) fields. Non-Player Character (NPC) in a video game is an appropriate example as the intelligent agent. This article focuses on researches about an intelligent agent with feelings and emotions as IUI and introduces theories and technologies related to them.

This article is organized as follows. The next section introduces popular researches about emotional theories and emotion models which are frequently referred by *Affective Computing* (Picard 1995) researches. Then, in the Section of "Intelligent Agents with Feelings and Emotions", several related researches about intelligent agents with feelings and emotions are introduced, e.g., Intelligent Virtual Environment (IVE), emotion recognitions, and so on. Afterward, Section 4 explains future visions

and state-of-the-art technologies about *Affective Computing* researches. The section especially focuses on Deep Learning technologies, which is one of the hot topics in AI and CI fields, and considers its possibilities to be adopted to the intelligent agent. Finally, Section 5 concludes this article.

Emotion Theories and Emotion Models

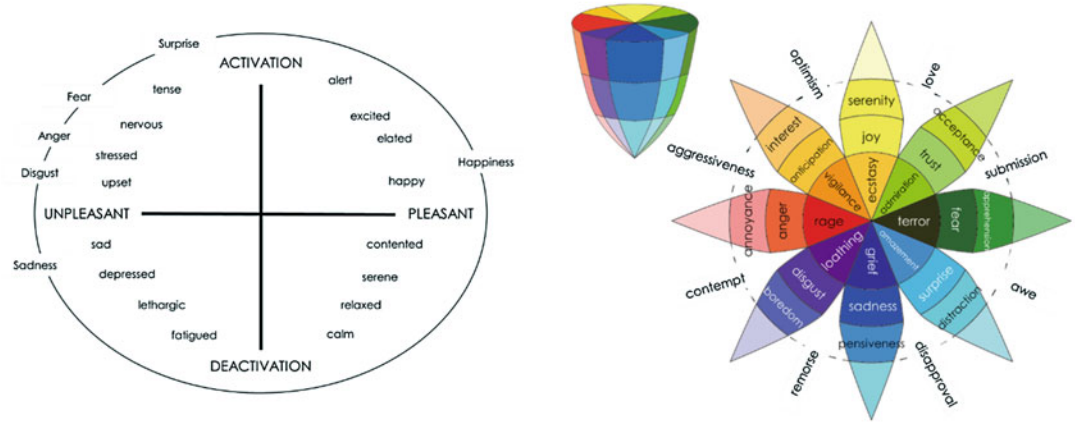
Emotion theories and emotion models are discussed from viewpoints of various research fields. One of the dominant theories is *Discrete* Emotion Theory. The theory considers emotions as discrete elements. One of the well-known researches in this theory is Ekman et al. (1982). They classified human's emotions into six discrete categories, *Joy*, *Sadness*, *Anger*, *Fear*, *Disgust*, and *Surprised*, based on their facial expression researches. As another model of categorizing emotions, Parrott represented emotions as a tree-structured list which consists of three types of categories: Primary emotion, Secondary emotion, and Tertiary emotions (Parrott 2001). The upper image in Fig. 1 describes the list. Another dominant theory is *Dimensional* Emotion Theory. The theory considers emotions as a combination of several psychological dimensions. Therefore, each emotion is not separated but continuously allocated on two or three dimensions. Posner et al. introduced emotions represented as a two-dimensional circular space which has two axes of *Arousal* and *Valence* (Posner et al. 2005). Emotion states are allocated in the circular space according to the values of the axis. The left-lower image in Fig. 1 depicts a circular style model. Plutchik's wheel of emotions is a popular example of the three dimensional emotion model (Plutchik 2001). The wheel model is described as the right-lower image in Fig. 1. He defined eight primary emotions. Each emotion has an opposite emotion: *Joy-Sadness*, *Trust-Disgust*, *Fear-Anger*, and *Surprise-Anticipation*. The primary emotions are allocated on the circle by degrees of similarity. Emotions allocated outside of the circle are mixture emotion of each neighbor primary emotions. The vertical dimension describes intensity of the primary emotions: the upper side means a high intensity state of a primary emotion and the lower one means a low intensity state of it. As different emotion theories from these, there are another approach to represent emotions as the relationship between a physical response and mental feeling. Several different theories, e.g., James-Lange's theory, Cannon-Bard's theory, and Schacter-Singer's Two-factor theory, are in the concept but the theories would be able to be divided into two concepts: Appraisal Theory (Emotion Drives Behavior) or Constructivist Theory (Behavior Drives Emotion). In the case that a human encounters a bear, in Appraisal Theory, he trembles because he felt fear; meanwhile, in Constructivist Theory, he feels fear because he trembled. The OCC (Ortony, Clore, and Collins) model represents these relationships between emotions and behaviors (Ortony et al. 1998). Because the model is possible to predict an appropriate emotion in given situations, the most of researches about agents' behaviors use this model for implementing agents' emotion and behavior models. Figure 2 depicts the OCC model. The model describes a hierarchy structure and 22 types of emotion categories. The hierarchy has three branches about *Events*, *Agents*, and *Objects* in its situation. The model explains why an emotion occurs from the situation by retrieving these branches according to its situations. For example, consider a situation where there are two agents in a virtual environment, i.e., agent A and agent B, and predict an appropriate emotion of agent A in the following situations.

- Find a wallet that had been lost (*consequences of events*)
- The wallet is a thing of agent B (*consequences of others*)
- Agent B smiles (*desirable for other*)

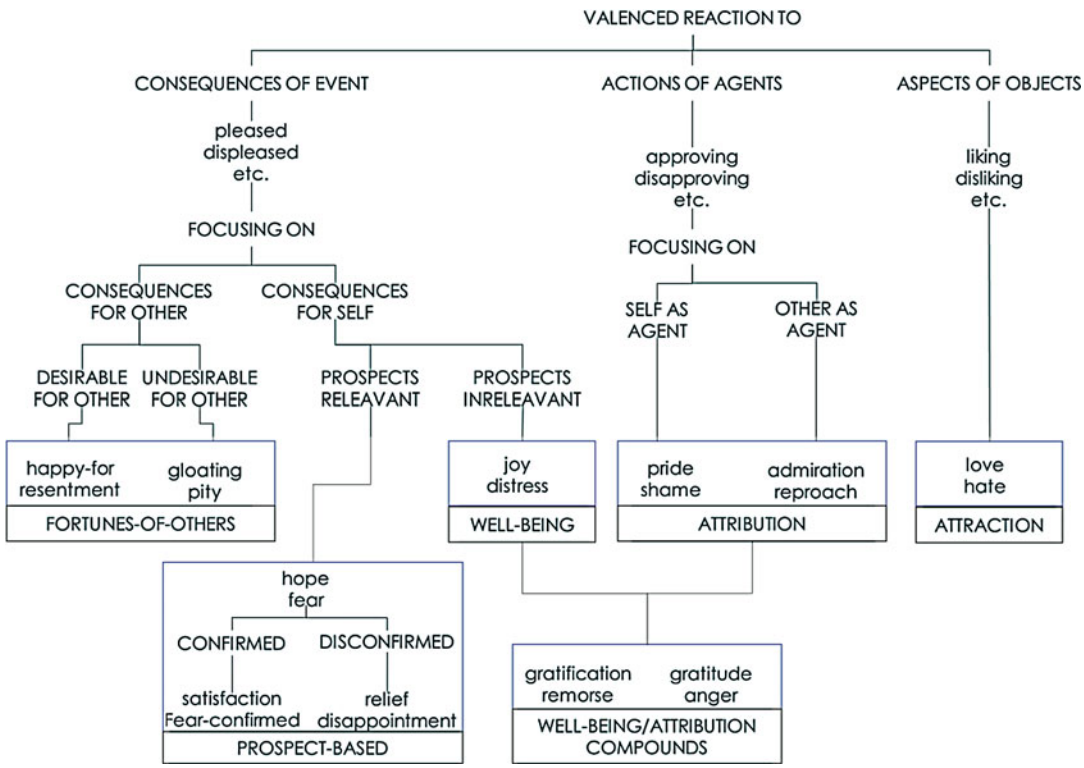
In these situations, the OCC model built-in agent A indicates *happy-for* agent B.

These introduced emotion theories are used for constructing emotion models for intelligent agents. The emotion models become a trigger to cause the agent's behaviors.

Primary Emotion	Secondary Emotion	Tertiary Emotions
Love	Affection	Adoration, Affection, Love, Fondness, Liking, Attraction, Caring, Tenderness, Compassion, Sentimentality
	Lust	Arousal, Desire, Lust, Passion, Infatuation
	Longing	Longing
Joy	Cheerfulness	Amusement, Bliss, Cheerfulness, Gaiety, Glee, Jolliness, Joviality, Joy, Delight, Enjoyment, Gladness, Happiness, Jubilation, Elation, Satisfaction, Ecstasy, Euphoria
	Zest	Enthusiasm, Zeal, Zest, Excitement, Thrill, Exhilaration
	Contentment	Contentment, Pleasure
	Pride	Pride, Triumph
	Optimism	Eagerness, Hope, Optimism
	Enthrallment	Enthrallment, Rapture
	Relief	Relief
Surprise	Surprise	Amazement, Surprise, Astonishment
Anger	Irritation	Aggravation, Irritation, Agitation, Annoyance, Grouchiness, Grumpiness
	Exasperation	Exasperation, Frustration
	Rage	Anger, Rage, Outrage, Fury, Wrath, Hostility, Ferocity, Bitterness, Hate, Loathing, Scorn, Spite, Vengefulness, Dislike, Resentment
	Disgust	Disgust, Revulsion, Contempt
	Envy	Envy, Jealousy
	Torment	Torment
Sadness	Suffering	Agony, Suffering, Hurt, Anguish
	Sadness	Depression, Despair, Hopelessness, Gloom, Glumness, Sadness, Unhappiness, Grief, Sorrow, Woe, Misery, Melancholy
	Disappointment	Dismay, Disappointment, Displeasure
	Shame	Guilt, Shame, Regret, Remorse
	Neglect	Alienation, Isolation, Neglect, Loneliness, Rejection, Homesickness, Defeat, Dejection, Insecurity, Embarrassment, Humiliation, Insult
	Sympathy	Pity, Sympathy
Fear	Horror	Alarm, Shock, Fear, Fright, Horror, Terror, Panic, Hysteria, Mortification
	Nervousness	Anxiety, Nervousness, Tenseness, Uneasiness, Apprehension, Worry, Distress, Dread



Emotion-Based 3D CG Character Behaviors, Fig. 1 Emotion models: the upper image is Parrott' model, the left-lower one is Posner et al. model, and the right-lower one is Plutchik's model



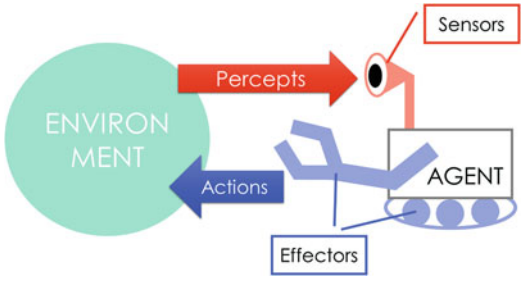
Emotion-Based 3D CG Character Behaviors, Fig. 2 OCC (Ortony, Clore, and Collins) model

Intelligent Agents with Feelings and Emotions

The term of *Intelligent Agent* is defined in various interpretations around AI and CI fields. According to the book written by Smith et al., Kasabov in 1998 defined the characteristics an intelligent agent should exhibit as followings (Smith et al. 2009).

- Plan, learn, and improve through interaction with the environment (embodiment)
- Adapt online and in real time
- Learn quickly from large amounts of data
- Accommodate new problem solving rules incrementally
- Have memory-based exemplar storage and retrieval capacities
- Have parameters to represent short- and long-term memory, age, forgetting, etc.
- Be able to analyze itself in terms of behavior, error, and success
- Have the ability to represent and reason over knowledge
- Have "social intelligence" for effectively interacting with other Artificial General Intelligent agents

Russell and Norvig also defined an agent as *anything that can be viewed as perceiving its environment through Sensors and acting upon that environment through Effectors* (Russell and Norvig 1995). The agent model is described in Fig. 3. In the case of a humanoid robot, the *Sensors* would be eye-cameras for recognizing things and ultrasonic sensors for detecting distances from other things and the *Effectors* would be arms and legs for influencing their environment which would be real-space. This article treats *Intelligent Agent* as a software program which has ability to autonomously behave according to changing conditions in its environment including *Virtual* and *Real* space by using the *Sensors* and the *Effectors*. In the virtual space, intelligent



Emotion-Based 3D CG Character Behaviors, Fig. 3 Russell's and Norvig's intelligent agent model

agents perceive information from their virtual environment and behave according to their purposes. Such virtual environment containing intelligent agents is called Intelligent Virtual Environment (IVE). Aylett and Luck defined IVE as *combination of intelligent techniques and tools, embodied in autonomous creatures and agents, together with effective means for their graphical representation and interaction of various kinds* (Aylett and Luck 2000). Namely, IVE is a study field of merging Virtual Reality (VR), AI, and Artificial Life (AL) fields. As a research about agents with feelings and emotions in IVE, Liu1 and Pan introduced an emotion model of 3D virtual characters in IVE (Liu and Pan 2005). The virtual characters have the ability to perceive current environment conditions in their virtual space, e.g., a forklift is closing to them, and they can express their emotion by their body pose movements and their facial expressions. A lot more IVE researches and applications appear in the survey paper written by Aylett and Cavazza (2001). Researches for constructing an emotion model to operate the *Effectors* are important theme to implement an intelligent agent. Egges' approach can be helpful to build the emotion model and the agent's behaviors as the *Effectors* (Egges et al. 2003). The authors provided a generic model for personality, mood, and emotion simulation for conversational virtual humans. The personality and emotion model was developed based on the five personality factors, i.e., *Openness*, *Conscientiousness*, *Extraversion*, *Agreeableness*, and *Neuroticism*, and one good-bad mood dimension. Additionally, the authors used the 24 emotions based on the OCC model to express agent's emotions by using facial animations. The model was applied to their prototype application which has a dialogue system and a talking head with synchronized speech and facial expressions. As researches for the *Effectors* which express agents' feelings, Raouzaiou's facial expression research is useful (Raouzaiou et al. 2002). Raouzaiou et al. defined basic facial expressions of six emotions based on the Ekman's emotion theory using Facial Animation Parameters of the MPEG-4 specification. Egges and Thalmann's research about an emotion model and body animations with its emotions for a 3D character can be available to implement intelligent agents in virtual environment (Egges and Thalmann 2005). The authors introduced an idle motion engine which was adopted 2D emotion space with activation-evaluation axis and can generate realistic looking animations according to its emotional state. Several researches tried to develop an authoring system to build these emotion model and agents' behaviors. BAAP (Behavioral Animation Authoring Platform) developed by Li et al. is one of such systems (Li et al. 2010). They implemented agent's emotion model by using 2D emotion model which contains six emotions, *Happiness*, *Sadness*, *Anger*, *Fear*, *Surprise*, and *Disgust*, and agent's behavior was controlled by a *Behavior Tree* in which a leaf node represents a behavior of the agent. The tree structure was implemented based on the OCC model. The authoring system can customize an agent's personality by operating an interface of the behavior tree. They introduced a story scene as an experimental result in where two different stories are generated by changing agents' personalities. As another approach, Loyall et al. (2004) developed an authoring system which can build a 3D character's personality including its emotion. The system controls their 3D character by script languages. Popescu et al. developed an emotion engine for a NPC in a video game (Popescu et al. 2014).

By changing the perceptive target of the *Sensors* from virtual-world to real-world, the intelligent agents can be adopted to IUI. Namely, the agent can percept humans' behaviors such as

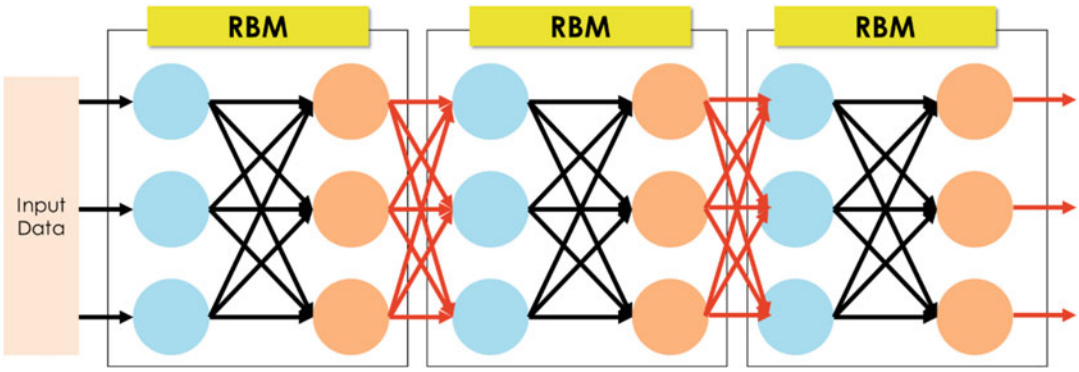
facial expressions, conversations, and gesture poses, and act in the virtual-world according to the real-world conditions by operating the *Effectors*. In a case of the intelligent agent with feelings and emotions as IUI, the functionalities of the Sensors and Effectors can be handled as those of emotion detections and recognitions from humans' behaviors. Azcarate's recognition method classified seven emotions, *Happy*, *Surprised*, *Angry*, *Disgusted*, *Afraid*, *Sad*, and *Neutral*, from facial expressions by using Naive Bayes Classifier (Azcarate et al. 2005). Castellano et al. recognized human emotions from gestures (Castellano et al. 2007). They focused on a velocity, acceleration, and fluidity of the hand's barycenter in continuous gestures. As a research of intelligent agents as IUI, Kaneko and Okada introduced a system for the agents who understand human emotion and express the emotion by facial expression (Kaneko and Okada 2014). The agent can receive voice input data from a microphone and convert it to text data. The text data was interpreted by an emotion word database and the agent express the emotion as a facial expression. In video game fields, such Affective Computing research is called *Affective Gaming* (Gilleade and Dix 2005). Bacivarov and Corcoran tried to apply facial expressions to video games (Bacivarov and Corcoran 2009). A lot more researches and applications about *Affective Gaming* are summarized in the survey paper written by Kotsia et al. (2013).

Future Visions and State-of-the-art Technologies

In the future, intelligent agents with feelings and emotions as IUI will play increasingly important roles to connect a human and a computer in various application fields. In Virtual Reality (VR) fields, we might spend our daily life for in IVE by using a head mount display and haptic devices. A 3DCG character as an intelligent agent, in the situation, will become a helper for psychological therapies and physical rehabilitations. Augmented Reality (AR) and Mixed Reality (MR) can be available in another field for the intelligent agents to play an active role. The agents might be able to become a navigator on maps and a supporter for our learnings. We can feel these possibilities of intelligent agents from the survey paper of Virtual Learning Environment (VLE) by Pan et al. (2006). Although it is different from VR, the concepts of the intelligent agents and method to build emotion models can be adopted to *Reality* field, e.g., robotics technology. A robot which has sensors used to understand humans' emotions and abilities to express his/her feelings is one of the ideal intelligent agents and can become a good partner for human beings. The affective robot research of Breazeal shows us the possible future visons (Breazeal 2003).

Because IUI is closely related to AI and CI fields, in the future as well as current situation, the researches and technologies about intelligent agents as IUI will evolve with these fields. In AI and CI fields, these days *Deep Learning* (Deng and Dong 2013) becomes one of the hot topics. Deep Leaning is a set of machine learning algorithms using Artificial Neural Network (ANN) piled in multilayers. Figure 4 depicts one of the Deep Learning architectures: Deep Boltzmann Machine. The advantage of the algorithm is that we need not extract feature values for pattern recognitions: the algorithm extracts them. The algorithm treats raw data, e.g., pixel data, as input data for input nodes of ANNs in which feature values are extracted and the extracted feature values as output data of the ANNs are used for input data of another ANNs in another layer. ANN structures as the learning model have been devised in resent researches. Deep Boltzmann Machines (DBM), Deep Belief Networks (DBN), and Convolutional Neural Networks (CNN) are popular architectures in the Deep Learning field. A lot more Deep Learning architecture appears in the document written by LISA lab (LISA lab 2015). Deep Learning has powerful possibilities to advance the intelligent agent technologies. The remainder of this section focuses on the state-of-the-art researches about Deep Learning which can be adopted to the intelligent agents as IUI.

In the video game research field, there are several interesting researches which have



Emotion-Based 3D CG Character Behaviors, Fig. 4 A concept of Deep Learning architecture: the RBM in the figure means Restricted Boltzmann Machine

potential to be adopted to intelligent agent behaviors. Mnih et al. introduced a Deep Learning research in which a machine trained by *Reinforcement Learning* method played Atari 2600 games and got high scores than a human expert in several games (Mnih et al. 2013). The authors used raw pixel data as input data for CNN and apply its output data to Q-Leaning, which is a kind of Reinforcement Learning method. Although the research target is not the case of in 3D VR world, the method might be hints for developing intelligent agent behaviors in video games. As a research about 3D video games, the approach of Min et al. provides interesting results to think behavior models for the intelligent agent. The authors introduced a goal recognition framework for *Open World* game (Min et al. 2014). The research used action log data of game player in a first-person viewpoint game as training data set for Stacked Denoising Autoencoders (SdA), a kind of Deep Learning architecture. The action log data are categorized into five parts: *Action Type*, *Action Argument*, *Location*, *Narrative State*, and *Previously Achieved Goals*. The research obtained results of outperforming the previous goal recognition approach based on Markov logic networks. The concept to apply player's action data in VR to machine thinking and decisions will be useful to develop intelligent behaviors of human-like agents.

Away from researches around intelligent agent behaviors, then, we focus on researches around Affective Computing for detecting and recognizing human emotions. Neagoe et al. introduced several Deep Learning model for facial emotion recognition (Neagoe et al. 2013). The research focused on models based on CNN and DBN. The models recognized seven emotion categories, *Happiness*, *Sadness*, *Surprise*, *Anger*, *Disgust*, *Fear*, and *Neutral*, by using facial images in JAFFE database. The emotion recognition results got high scores than the results of other benchmark algorithms: Nearest Neighbor (NN), Support Vector Machine (SVM) with RBF kernel, and SVM with linear kernel. Albornoz et al. introduced an effective method to classify seven emotions, *Anger*, *Boredom*, *Disgust*, *Fear*, *Joy*, *Sadness*, and *Neutral*, from speech utterances data by using RBM and DBN which obtained better scores than a multilayer perceptron classifier (Albornoz et al. 2014). Although Neverova et al. approach which detects gestures by using Deep Learning method is not for emotion detection, the concepts and methods might be applicable to the human emotion detection (Neverova et al. 2014). Martínez et al. investigated the utility of Deep Learning approaches for modeling affects comparing several types of CNNs. The authors tried to find emotional manifestations of *Relaxation*, *Anxiety*, *Excitement*, and *Fun* form skin conductance signals and blood volume pulses while a user play a video game (Martínez et al. 2013). Emotion recognition from Electroencephalogram (EEG) by using Deep Learning method is one of the futuristic approaches. Jirayucharoensak et al. applied

power spectral densities of 32 channel EEG signals to their recognition method based on Stacked Autoencoders which classified nine emotion states: *Happy*, *Pleased*, *Relaxed*, *Excited*, *Calm*, *Distressed*, *Miserable*, *Depressed*, and *Neutral* which are allocated in Valence-Arousal dimensional emotion model (Jirayucharoensak et al. 2014).

These state-of-the-art technologies about agent behaviors, emotion detections, and emotion recognitions will become useful hints to develop intelligent agents with feelings and emotions as IUI as future works.

Conclusion

This article introduced several researches related to intelligent agent works as user interfaces which can understand humans' emotions and can behave against them. Recently, these fields become more hot tops because several breakthrough researches focused on Deep Learning technologies. These results of the researches would be applied to robotics fields. According to the advancement with these researches, an intelligent agent as a user interface communicating with a human would be discussed with many research fields. Because the researches treat several study fields, e.g., *Virtual Reality* and *Artificial Intelligence*, in the future as well as current situations, the researches will evolve with these related fields. These challenging researches will make more friendly relationships between human beings and computers, and enable to build a coexisting society of them.

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Engagement

▶ Game Design and Emotions: Analysis Models
▶ Virtual Reality as New Media
▶ Virtual Reality: A Model for Understanding Immersive Computing

Engaging Dogs with Computer Screens: Animal-Computer Interaction

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Synonyms

ACI; Animal-computer interface; DCI; Dog technology; Dogs

Definition

Animal-computer interaction (ACI) and dog-computer interaction (DCI) are extensions of human-computer interaction (HCI), which refer to the usage of technologies for animals and dogs, respectively. However, HCI refers to usage of technologies for humans.

Introduction

Animal-computer interaction (ACI) includes developing a video game prototype for canines. This entry aims to provide context for the problem of attracting dogs to watch screens; the solutions that have been presented, with aims, objectives, and functional/nonfunctional requirements; the perspective that this project makes to the research field of ACI; and the scope of the entire project (Mancini 2016).

ACI is a relatively young but expanding field of research with a lot of progress made in recent years all across the world. However, there are still a number of questions that need answering, such as the following: How do we change the design of human applications to allow animals to interact with them (Mancini et al. 2012; Mancini 2013, 2017)? How can we have animals use technology without human assistance (Hirskyj-Douglas and Read 2014)? What kind of applications benefit animal welfare (Geurtsen et al. 2015; Broom 1996; Rehn and Keeling 2011)? How can we analyze how dogs feel about the applications that we present them with (Baskin et al. 2015; Mankoff et al. 2005).

All of these questions are being asked so that researchers can understand how to properly design various hardware and software for future ACI projects, particularly for dogs. However, although these questions are important in the design of the research, the main question that authors are trying to solve with it is: What can be done to attract dogs to a computer screen in order to use the application created for them?

One of the most essential steps in ACI design is getting the dogs to initiate interaction with the application; however, in order to do that, they need to be interested in interacting with the application in the first place. To achieve this, developers of ACI applications need to establish appropriate techniques that they should be employing in the design of their applications. The problem, however, is that there are no definitive ways of implementing this essential step in ACI design. This leads to extra time and resources being spent by developers trying to understand what exactly they can do in order to solve this problem themselves. A comprehensive review is needed in detail of the various solutions which researchers in the field have produced, to see which ones can be generally applied to each type of application, based on the nature of the hardware and software that are need for the developing stage.

To design and implement any interactive application for animals (Zeagler et al. 2014) in the form of a video game prototype that attracts the attention of dogs and be useable by them (Nielsen 1995; Kjeldskov and Graham 2003), some main steps are required which will be discussed in this entry. This means designing the application using various UML diagrams and techniques; developing a demo via chosen programming language; and having a selection of test participants (all canine) to interact with it, under ethical conditions (Grillaert and Camenzind 2016), in order to ensure that the application meets the specified requirements. The most important aspect usually is to ensure that the video game is fit for purpose. This is the most crucial part of the study, as cannot be solved the main problem of understanding what attracts canines to screens without ensuring that it is certainly a video game with which dogs would be interested in interacting. Otherwise, it would be pointless to have controlled experiments, as they are more than likely to ignore anything that is not designed with them in mind. This research references to what dogs are interested in and looks to incorporate those interests in the video game, in order to come up with the list of interests for dogs in the field of ACI.

Methods

Giving the canine incentive to notice and pay attention to the screen which your application is being displayed on is one of the most essential steps in initiating interaction between dogs and software. This is evident in the experiments that has been researched which all used some technique to attract dogs to their own screens (BBC 2018; Baskin et al. 2015; Geurtsen et al. 2015). The use of techniques like this can also provide additional benefits to familiarize dogs with the hardware that researchers want them to use, such

as the experiment by Dr. Lisa Wallace whose use of screen paste taught dogs how to interact with their own touchscreens using their tongues. Various such techniques will be documented, and their effectiveness will be detailed within this entry, so that researchers can understand why they are important and possibly use them in their own experiments (Burghardt 2005).

Placing Confectionery Items on a Screen

One of the more unique techniques for attracting dogs to a screen that researchers and scientists have been using as of late is to place confectionery items on the screen of the computer/tablet. Dr. Lisa Wallace from the Eötvös Loránd University has been using this technique in order to try and get dogs to interact with their brain training program on a tablet touchscreen. They would first smear a flavored paste all over the touchscreen without turning on the tablet and have the canines lick it off. They would then start the application and smear some more paste on the screen to have the dogs make contact with the application using their tongues. Once the application detected them touching the screen, they would receive a dry treat from a dispenser below the tablet; after some time, paste was no longer required to convince the dogs to lick the touchscreen and interact with the application, as they had now learned how to interact with it as the scientists had intended (BBC 2018).

Sound Design

One of the best senses that dogs possess is their ability to hear, which is generally considered better than that of humans. Their hearing spectrums range from 40 hz to 60 khz (Jensen 2007), and moreover they can locate the source of distinctive sounds (Geurtsen 2014). As stated earlier, we want dogs to exhibit playful behavior and hunting instincts with the prototype, and thanks to this excellent hearing range, certain sounds can be used to help initiate this behavior when it is needed to interact with the video game. The sounds that dogs will react to can vary on a case by case basis: some may prefer the sounds generated by squeaky toys if they particularly enjoy playing with them, or if a dog prefers hunting small animals, then it would probably respond to sounds that they would expect to hear from small animals, e.g., mice rustling through grass (Singer 1995).

A case has been made for this by researchers Golbeck and Neustaedter (2012), who in their project to design a pet monitoring device (for pet owners and canines to call and interact with each other) used a soundboard (among other ideas) to attempt to attract dogs to their prototype system. The soundboard consisted of sounds such as dog barks/howls, cat sounds, squeaky toys, and other sounds that they believed would interest dogs and could be activated remotely by the pet's owner to play the sounds through the monitoring system. In their experiment to have dogs interact with their monitoring system, they would have human users use the soundboard to attract their dogs to a pre-placed laptop screen in order to start interacting with their pet through the monitoring system. All but one of the dogs successfully came to the screen, the lone exception being a golden retriever that was too excited to pay attention to the sounds being played (Golbeck and Neustaedter 2012). One of the best ways to recognize what sounds dogs would want from an application would be the use of dog personas gathered from canine participants (Hirskyj-Douglas et al. 2017).

Laser Pointer and Visual Cues

The same experiment mentioned above also attempted to make use of the dog's visual sense by two different means. The first was a laser pointer, and the second a virtual object in the form of a tadpole, both of which were displayed remotely on the screen.

Discussion

This section contains discussions on the effectiveness of each technique and what have been considered in existing methods to make them engaged as much as possible.

Placing Confectionery Items on a Screen

Placing confectionery items on a screen has proven to be very useful for the particular experiment demonstrated as they managed to show how

useful it was for training dogs to use their devices with their tongues. Eventually they managed to have their dogs use the tablet device without the need for confectionary pastes on the screen, proving that this is indeed a great technique for having dogs engage with a computer screen.

There is only one problem with this technique, which is that it really requires specific equipment in order for anyone to make use of it properly. In the experiment, it was specified that the confectionery items they placed on their tablets was a flavored paste that was completely smothered all over the screen for the dogs to lick off. The problem with this is that most computers are not designed to have any kind of confectionery item, let alone flavored paste, smothered over their displays. There should be a few exceptions such as the devices they used in their experiment. (Note: The devices used in the experiment were not specified in the information source that have been examined (BBC 2018).) However, it would require dog owners to go out of their way to find that equipment if they want to try this technique themselves. Most dog owners would be completely averse to trying this technique, so as not to risk causing any kind of damage to their own computers due to the use of paste on their displays. This particular technique has not been taken into account as there was no access to the necessary technology, but there are rooms to acquiring the means necessary to try it in the future.

Sound Design

The use of specific sounds in DCI seems to be the most viable and generally best method for attracting dogs to a screen. This is for several reasons, the first of which is that dogs very much respond to recognizable sound effects and will tend to locate the source of recognizable sounds as soon as they hear them; therefore it should theoretically lead them to the computer, which they will investigate upon realizing that it is the source of the sound. Again, this has been proven by the experiment by Jennifer Golbeck who had almost all the participants in their experiment attracted to the screen via their own pre-developed soundboard (Golbeck and Neustaedter 2012).

Another reason for this being a viable technique is that it is a very easy method to use for attracting dogs to the screen, since all you really need is a variety of sound files that would attract the attention of canines upon hearing them. Developers of dog-centered applications and dog technology should be able to make use of this technique in some form by implementing sound files within their projects.

The only problem that some people would have with this method is that developers would have to take time to research what kind of sounds dogs would be interested in. This is to ensure that they use as many as possible within their projects, as some dogs may not have the same interest in certain sounds as others. Dog owners would need to experiment themselves and see which sounds from the variety that developers have provided catches the attention of their particular canine.

In the experiments with this technique, the majority of the participants expressed a moderate to great amount of interest toward the computer when sound effects are used in the video game prototype, particularly squeaky toy sounds. Some of their behavior patterns indicated interest toward the source of the sound as they would bark and jump toward the screen recognizing it as the source of the sound. However, the only problem is that during the experiments, one of the canines was confused by the sounds, as they would attempt to stick their nose and paws underneath the stool that the host device was placed on. This indicated that the canine did not recognize the laptop as the source of the sound and instead was looking for a squeaky toy underneath the stool.

Laser Pointers and Visual Cues

Judging by the research, this technique may not be as viable as the other methods described earlier, as proven by the experiment by Jenifer Golbeck et al. In their own experiment, they tried to attract the attention of dogs with both a laser pointer and a tadpole game playing on their computer screen, but with little success of attracting the dogs successfully to the screen (Golbeck and Neustaedter 2012). This is

because these objects were simply not very interesting to the canine participants, as other experiments have managed to successfully attract dogs to screen via screen cues, such as the one done by Sofia Baskin et al. Their experiment used two different kinds of visual cues, both a ball and mouse type object that would move around the screen. It was reported in this entry that both of the canine participants used in this experiment had taken interest in the objects by exhibiting certain behavioral patterns that indicated this (Baskin et al. 2015). That leads me to conclude that the use of visual cues can only work on a case-by-case basis for canines as they are only individually interested in certain objects.

If developers want to use visual cues, then it would be wise to implement a variety of objects in their projects to ensure every dog they work with has something that will interest them. However, depending on what kind of application they are developing, they will either have to develop these cues themselves, which take a lot of time and work, or get them from somewhere else, such as the Unity Asset Store. The latter option can be considered very expensive, depending on what kind of assets the developer needs, how many they need, and whether they are made at the quality level that the developer needs them to be at in order to use them properly.

Conclusion

When comparing all three options for attracting canines to a screen, it is safe to say that the most viable method that developers can utilize is the use of sound cues. This is due to various facts including that any sounds that developers require are easy to access and, in most cases, do not have any drawbacks to downloading them, such as fees; they are very easy to implement in most software applications aimed toward dogs; and they have been proven to be the most successful method when tested with a large range of dogs (Golbeck and Neustaedter 2012).

However, this does not mean that the other two methods are nonviable, as they each have their own useful factors for attracting dogs to a screen. Factors such as teaching fogs on how to use a touchscreen with their tongues, as well as to attract them to the screen, and keeping them engaged with the screen for a prolonged period of time when they notice that something of interest is there have been investigated by Baskin et al. (2015).

Overall, the viability of each method depends largely on the kind of hardware and software that DCI developers are using for their particular project. The viability also depends on the variety of assets used with each method and how well they use them for getting the dogs' attention. If the available options for each method are researched well, chosen well, and implemented to the highest standard expected of them, then they should overall have success in attracting dogs to their computer screen.

Cross-References

- ▶ Computer Go
- ▶ Game Development Leadership Tips
- ▶ Interaction with Mobile Augmented Reality Environments

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Engine Architecture

► Panda3D

Enhanced Visualization by Augmented Reality

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Synonyms

Augmented reality displays; Visualization techniques in augmented reality

Definition

Augmented reality is a combination of technology and interaction techniques to superimpose virtual objects onto the real world. Data or information visualization aims to provide visual ways to help users to fastly comprehend and interpret data, mainly when the subject is abstract. As such, there are different approaches to enhance visualization using augmented reality.

Introduction

Augmented reality (AR) can be defined as a variation of virtual reality (VR) in which virtual objects are superimposed onto the real world (Azuma 1997). It can also be understood as one class of displays in the reality-virtuality continuum (Milgram et al. 1995).

Importantly, augmented reality systems share three characteristics: combine virtual and real objects, allow real-time interaction, and perform

3D registration (Azuma 1997). Each of these requirements can be met by different technologies, as well as metaphors, which are explained in this text.

Visualization can be defined as the use of visual representations, sometimes interactive, to enlarge cognition and, thus, help users to comprehend and interpret abstract data (Gershon and Eick 1997; Card et al. 1999; Liu et al. 2014). Visualization enhanced by AR uses techniques of AR to enlarge cognition in three-dimensional interactive environments joining virtual and real objects.

Examples of Enhanced Visualization by Augmented Reality

This section presents a few examples of existing and potential systems in which information visualization is enhanced by augmented reality. Those examples are useful to give context to the technologies and techniques discussed later.

Visualization of Invisible Phenomena

Augmented reality can be used to provide visual information about phenomena, such as electromagnetic fields, which are not visible to the human eye. Similarly, it can display consolidated information that might be distributed or occluded; the system proposed by Bhattarai et al. (2020) aims at improving situational awareness of firefighters in a fire environment.

Enhancing the Study of Art Works and Cultural Heritage

Augmented reality systems might be used to visualize additional information over paintings, such as layers of pigment, construction lines, as well as highlighting separate subjects. A number of mobile augmented reality systems have also been developed to enhance the visitation of cultural heritage sites by presenting layers of additional information and virtual reconstructed buildings and other objects (Vlahakis et al. 2001) (Choudary et al. 2009).

Facilitating the Process of Architectural and Interior Design

Applications of augmented reality have been developed to provide visualization of furniture for design and decoration (Viyanon et al. 2017) (Nasir et al. 2018). The main motivation is to provide a cost-effective solution to experiment with different options and configurations of furniture. For this purpose, marker-based and markerless solutions are deployed, so that 3D models of furniture in actual scale can be visualized in a room and thus, space constraints, as well as aesthetic concerns, can be evaluated.

Improving the User Experience in Retail Applications

There are augmented reality systems that improve user experience by showing additional layers of information that are relevant to the users. Two examples are: displaying nutritional information on images of actual food (Jiang et al. 2018), and allowing the user to try virtual shoes, visualizing pressure points on the feet (Bizen et al. 2021).

Augmented Reality Display Technologies

Augmented reality (AR) is a concept instead of a specific technology. Therefore it is possible to implement such a concept using different solutions. Following, it is presented the most common technologies used in AR for displaying spatially registered visual information onto the real world.

Handheld/Mobile

Mobile applications are the most popular way of enhancing visualization via AR. Almost all current smartphones and tablets incorporate all technologies necessary for capturing real-world scenes, tracking movements, and superimposing registered visual information over the real world. Only a software layer is required to produce the AR effect. The most commonly used metaphors are “window” and “mirror.”

Desktop/Large Screens

Before mobile technology has incorporated high-quality video processing and tracking technologies, the most common way of producing AR was via desktop displays or large screen projections (via datashow). The "mirror" metaphor was most used in this case, as the user watched his/her actions by looking at the display screen and not directly to where the action was taking place in the real world. In the beginning of AR popularization, the most common way of registering was based on cheap fiducial markers (see the section on tracking technologies).

Head-Mounted Display (HMD)

Goggles, technically known as HMDs (head-mounted displays) in VR and AR applications, are mostly used in professional or public installations, due to high costs and complexity involved in setting up and use. It is expected that in the future those goggles would be as cheap and easy to use as sunglasses, which would eventually surpass smartphones and tablets as the preferred mobile solution for AR. There are two main approaches for producing AR effect via goggles: optical see-through and video see-through.

Optical See-Through

In this approach, a semitransparent screen is used, allowing the direct visualization of the real world while showing registered superimposed virtual images, digitally produced on that screen.

Video See-Through

It is basically a VR HMD, combined with a video camera that captures the real-world scene, which is augmented with registered superimposed digital synthetic elements. What the viewer sees is totally digital, but the sensation is of watching directly to the real environment with AR effects.

Projector-Based (Spatial AR)

This solution avoids the use of HMD by projecting virtual images directly over physical objects, altering their perceived texture or even producing the illusion of movement.

Visualization Metaphors

Metaphor can be understood as a main principle of mapping an application domain to a visual universe (Averbukh 2001). In the design of human-computer interfaces, metaphors are used to provide a conceptual reference that might aid users in understanding abstract data. Thus, some behaviors and properties of the reference entity are represented or instantiated on the interface (Preece et al. 2015).

It is interesting to note that visualization metaphors are found most often in AR systems, in which the mediation of the display technology cannot be hidden from the user, such as handheld/mobile, desktop/large displays, and projector-based AR.

Mirror

The mirror metaphor is found in desktop/large screens and handheld/mobile AR applications in which one or more cameras are pointed at the user and a mirrored image, composited with virtual objects is displayed. It leverages the familiarity of interacting with and inspected one's reflected image in the plane of the mirror to promote the visualization of the virtual objects.

Window

The window, or sometimes lens, metaphor is also encountered in handheld/mobile and desktop AR applications. In this case, the display surface is used as a framed viewport to the enhanced visualization. As such, it is expected that the virtual objects can only be seen through the limited display area.

X-Ray Vision

The X-ray vision metaphor can be found in projective AR systems. The image with enhanced virtual elements is understood as a view of the inside of the objects onto which it is projected.

Customized Metaphors

In this type of metaphor, developers seek to include visual objects (e.g., images, icons, 3D

surfaces) in their systems to represent abstract data in order to help users to comprehend the dataset that is being visualized in an AR system.

Tracking Technologies

In AR systems, tracking refers to the process of identifying reference objects or locations in order to perform 3D registration of the virtual objects: the correct geometric alignment of those objects onto the real world. There are a number of approaches for tracking, which may be grouped into four categories: magnetic, vision-based, inertial, and GPS-based (Billinghurst et al. 2015).

Magnetic Tracking

Magnetic tracking involves a transmitter and one or more receivers of magnetic fields; the variations of that field's properties allow for the determination of each receiver's position and orientation in space. While magnetic tracking allows for fast and accurate tracking, it is also limited to small volumes in space, and it is sensitive to electromagnetic interference in the environment.

Vision-Based Tracking

Vision-based tracking involves the detection of features in an image captured by a camera, which can work with visible or infrared light. The features may have been added artificially, in the form of fiducial markers; they may also be naturally occurring in the real world, such as patterns of lines, shapes, or textures, which are detected by image processing algorithms. A fiducial marker is a piece of any material containing a nonsymmetric pattern used to define the place where a virtual object should be included in a real scene. The cheapest way of producing these markers is by printing an image in common paper. Fiducial tracking is comparatively simpler, but the requirement for markers added to the environment limits its applicability. Natural feature tracking is more flexible, but the related algorithms require more processing power. In both cases, vision-based tracking is influenced by factors such as lighting conditions, occlusion and the presence of unexpected objects in the scene, which can disturb the pattern recognition process.

Inertial Tracking

Inertial tracking makes use of inertial sensors such as gyroscopes and accelerometers attached to a tracked object, to determine its position and orientation. Those sensors are not susceptible to electromagnetic interference, but they are affected by drifting, which reduces their accuracy.

GPS-Based Tracking

The use of GPS tracking for augmented reality systems is feasible in outdoor environments, to determine the user's position relative to a large area. Due to precision limitations, it is often combined with other forms of tracking.

Cross-References

- ▶ History of Augmented Reality
- ▶ Mixed Reality
- ▶ Mixed Reality and Immersive Data Visualization

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Enjoyable Informal Learning

► Conceptual Model of Mobile Augmented Reality for Cultural Heritage

Enjoyment

► Videogame Engagement: Psychological Frameworks

Entertainment

► Professional Call of Duty Player Matthew "Nadeshot" Haag: An e-Sports Case Study

Escape Room

► ROP-Skill System: Model in Serious Games for Universities

Esports

► Call of Duty Franchise, an Analysis
► Diversity in Gaming and the Metaverse
► Counter-Strike Global Offensive, an Analysis
► Fortnite: A Brief History
► Professional Call of Duty Player Matthew "Nadeshot" Haag: An e-Sports Case Study
► Super Smash Bros. Ultimate and E-sports

Essential Experience

► Dark Souls Through the Lens of Essential Experience

Ethical Issues in Gamification

► Gamification Ethics

Ethics in Gamification

► Gamification Ethics

Ethnic Inclusiveness

► Diversity in Gaming and the Metaverse

Evaluation Model

► MEEGA+, Systematic Model to Evaluate Educational Games

Everyday Virtual Reality

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Synonyms

Immersive technologies; Mixed reality; Virtual reality; Virtual systems

Definition

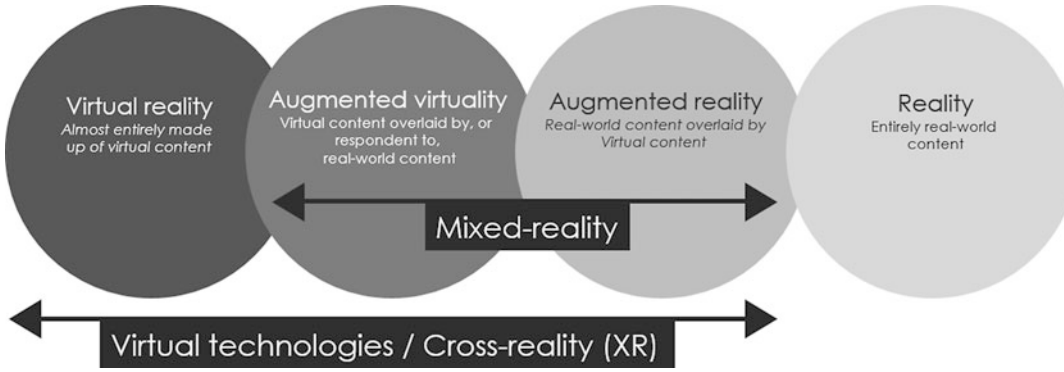
Everyday virtual reality (VR) can describe any activity that the majority of us would typically engage in at least once per day, experienced through the medium of VR. Its meaning is interwoven with user experience and the concept of technological acceptance, which describes users' feelings toward a technology's design and its intended purpose. In some contexts, VR already functions as an accepted and almost ubiquitous part of everyday life, while in others, it remains a novel technology – but one with great potential for ubiquity in the near future.

Introduction

First coined in 1987 by Jaron Lanier (see Slater and Sanchez-Vives 2016), the underlying meaning of VR is one that has broad similarities but also slight differences between its various definitions. VR definitions broadly fall into one of two categories, one more technology focused and the other more centered upon user experience. The technological definition describes VR as multidimensional, computer-generated content that is perceived by a user as a continuous and distinct environment (Craig et al. 2009; Seidel and Chatelier 2013). The user experience definition by comparison explains VR in terms of "presence" (feeling physically/cognitively that you are *in* an environment). Steuer (1992), for instance, argues that to be considered VR, a system should evoke a degree of presence in the virtual world that is approaching our sensation of presence within the physical world. In further delineations, VR using head-mounted displays (HMDs) is normally termed "fully immersive VR," with "semi-immersive VR" referring to the use of flat screen displays. Additionally, there is the issue of the reality-virtuality continuum (Milgram and Kishino 1994) which encompasses VR, augmented reality (AR), and augmented virtuality (AV) – all broadly outlined in Fig. 1.

By popular definition, VR is again defined technologically, but in more restrictive terms. Here, VR describes a system using a consumer-grade HMD with head and/or body tracking. This article will focus primarily upon VR by the popular definition, looking at the use of contemporary PC and mobile VR devices in everyday purposes. The rationale for this focus is that, as the term would suggest, popular VR encompasses the technology most available to the general public, with its development largely dictated by user experience requirements in everyday use contexts.

Everyday VR emerged as a more formal concept in 2015, with the first IEEE Workshop in



Everyday Virtual Reality, Fig. 1 Edited version of Milgram and Kishino's "reality-virtuality continuum"

Everyday Virtual Reality (Simeone et al. 2015a). Here the concept is described as the use of consumer-grade VR technology in an everyday setting, such as a domestic or office environment.

Current Everyday VR Technology

Broadly speaking, consumer-grade VR technology can be separated into four main classes based on their platform; PC-based (also known as "tethered VR" – *Oculus Rift*, *HTC VIVE*), smartphone-based (*Samsung Gear VR*, *Google Cardboard*), console-based (*PlayStation PSVR*), and most recently, standalone mobile platforms (*Oculus Go*, *Lenovo Mirage*). Each class of VR comes with a unique set of advantages and disadvantages, with each proving more capable in certain contexts while less capable in others. Table 1 below summarizes these pros and cons across each platform class.

Speaking again in more general terms, tethered and smartphone systems are largely presented to consumers as antitheses of one another, with the majority of one platform's advantages mirroring the other's disadvantages. Console systems are positioned somewhere in between on most points of evaluation while the newer standalone systems are more comparable to smartphone VR, but largely differentiate themselves with improved optimization – being built bespoke for VR. Throughout this article, we shall refer back to these pros and cons to show how diversity in VR technology is supportive of its everyday use.

Everyday VR in the Home

Recreational use is undeniably the primary way in which everyday VR has infiltrated our homes. Though the function of VR in the home began with video games, the technology has quickly been developed to support our interactions with various additional forms of media. All four VR platforms support streaming of television and film, with all but console VR supporting web browsing – enabling users to interact with web-based content within an immersive VR environment.

Central to the evaluation of technology used for accessing media is the concept of user experience (UX). As Albert and Tullis (2008) observe, the defining requirements of positive UX are that the user feels involved, interested, and in control. Similarly, research concerning UX for web browsing indicates that the interface should essentially strive for perceptual invisibility, becoming an extension of the user to enable the most efficient and direct interaction with internet content (Yu and Kong 2016). This presents a significant challenge to VR which, as a novel consumer technology with different means of interaction (e.g., gaze selection in place of touch screen and mouse interfaces) is anything but invisible. As a result, VR faces a significant challenge in becoming a

Everyday Virtual Reality, Table 1 Summary of key advantages and disadvantages of VR, separated by platform

	VR platform			
	PC/Tethered	Smartphone	Console	Standalone mobile
Advantages	Visual fidelity Greater comfort (supports extended use) Integrated headphones 6 degrees of freedom (positional tracking) Motion controllers as standard Greater field of view (110°) Room-scale VR Highly adjustable HMD (straps, lenses)	Very low-cost headsets Uses hardware many of us already have Highly portable Easy to setup and operate Wireless reduces trip hazards More social More reliable Poor optimization (heat issues/battery intensive)	Very comfortable for extended use Integrated headphones Average FOV (100°) 6 DOF (positional tracking) Motion controllers as standard Easy setup and use More reliable	Better mobile optimization Highly portable More reliable More social Greater comfort Wireless reduces trip hazards Easy setup/use 6 DOF (limited) Controllers as standard Integrated headphones FOV (100°)
Disadvantages	High cost Requires powerful PC Requires large space Lacking portability Increased risk of trips and falls with wires More difficult to setup More liable to technical problems More isolated experience	Poorer visual quality More susceptible to frame lag, causing motion sickness Lacks positional tracking Controllers not standard Less comfortable for extended use Poorer FOV (90°)	Limited application (usage restricted to video games and media) High cost of both console and VR headset Lacking portability Lacking room-scale VR	Poorer visual quality More susceptible to frame lag, causing motion sickness More expensive than smartphone Room-scale VR is limited Less adjustable HMD

genuine alternative to PC and touchscreen smartphones interfaces; both of which have been heavily refined in terms of both usability and UX for many years (Lobo et al. 2011). Ongoing development in smartphone and computer interfaces also means that VR will likely be playing a perpetual game of catch-up.

Of the four VR platforms, smartphone systems arguably standout as the most appropriate for this particular everyday context; its accessibility, ease of use, and wireless operation all support the above UX requirements, while many of its limitations (poorer graphics, lacking positional tracking) are less applicable in this context. That said, issues such as extensive power consumption and heat generation limit users to significantly shorter sessions when compared to using a non-VR smartphone interface. Additional barriers to its technological acceptance include social issues, relating to feelings of social awkwardness in "wearing a computer" in public (Busel 2017).

More in the domain of academic research, "substitutional reality," features as a particularly interesting area of development. Simeone et al. (2015b) define substitutional reality as "a VR experience that incorporates physical objects into

the virtual world by using them to represent objects relevant to the virtual context" (p. 3307). The general idea is that real-world objects are tracked in virtual space and mapped to virtual objects that may be very different in nature, but comparable in their weight and dimensions. In this instance, a bottle may become a vial of magic potion, a broom a lightsabre, an umbrella may even become Mjolnir (Thor's Hammer). While not yet commonplace in our homes, substitutional reality is arguably an advocate for the "everydayness" of VR, as it utilizes a range of distinctly everyday objects about the home and repurposes them to create multisensory and deeply immersive mixed-realities.

Although VR is highly unlikely to replace traditional interfaces for 2D media content, it is in the third dimension where the technology has the most potential. 360° films and television programs can be viewed upon 2D screens but lack the immersive quality of head-tracked HMDs, to the extent that such content is essentially exclusive to VR. As the majority of web content is two-dimensional, however, there remain significant limitations to the perceived usefulness of VR for web browsing. That said, research is pursuing this issue by exploring various means of deploying immersive, 3D websites built upon existing web-standard technologies (de Paiva Guimarães et al. 2018). The future success of VR in this context remains an optimistic but unknown quantity.

In the Classroom

Virtual technologies are becoming increasingly notable within education and skills training. A recent meta-review by Gutierrez-Maldonado et al. (2017) noted that $1.2 billion has been invested globally in the last couple of years to increase access to virtual content, specifically by supporting the development of HMDs. This is not at all surprising as some of the fundamental characteristics of VR, namely the potential to create accurate and immersive simulations of real-world phenomena, are ideally suited to contextualizing and grounding complex and abstract information. A further review by Jensen and Konradsen (2017) observes that VR offers support to memory and spatial awareness training and can also help with the development of motor skills and emotion control. One of the most significant benefits of VR in classrooms relates to the concept of the "extended classroom" (see Loureiro and Bettencourt 2011), with the technology enabling students to engage with simulations of various locations and events that would be expensive, impractical, or even physically impossible to experience otherwise.

VR within an educational context has built upon the progress made by semi-immersive virtual systems; serious games that present the user with a three-dimensional world from a first-person perspective. A prominent example of this would be in the use of *Minecraft* (Persson et al. 2011) in schools. As Nebel et al. (2016) point out, games such as this are deeply supportive of constructivist pedagogy (contextualized learning through active construction of knowledge) and encourage cooperative learning, self-management and provide an accessible route to understanding complex systems. Minecraft is currently being used in numerous school systems all over the world to teach an impressively broad range of academic subjects (Short 2012). VR arguably provides key additional benefits beyond those offered by traditional serious games. These include greater perceived realism through more immersive audiovisual content and more naturalistic controls, and a deeper connection to the content through enhanced feelings of presence (see Freina and Ott 2015).

Although its advantages are distinct, the likelihood of seeing VR as a ubiquitous technology within this everyday context is dependent upon its disadvantages being overcome. Jensen and Konradsen (2017) note that the benefits of VR over traditional computer interfaces are largely limited to those stated above and that the technology also presents issues that can be counterproductive to learning, such as the prevalence of cybersickness and the potential of the immersive experience being a distractor from the learning task. One of the primary current issues with classroom VR is financial feasibility. Though

a far more significant issue 15 years ago (see Mantovani et al. 2003), the costs of purchasing, maintaining and supervising the operation of HMDs in the classroom remains prohibitive for many schools (Merchant et al. 2014). The investment mentioned above, however, seeks to overcome this issue by driving down the consumer costs of the hardware, making it more compatible with cheaper computers and developing the potential of smartphone-based VR (Gutierrez-Maldonado et al. 2017).

At the cutting edge, research into classroom VR is largely prioritizing developments in multiuser cooperative systems (Greenwald et al. 2017), integration of bio/neurofeedback (Blume et al. 2017), and designing for students with special educational needs such as autism and attention-deficit hyperactivity disorder (Neguț et al. 2017). In our current classrooms, fully immersive VR may not be as "everyday" for most students as semi-immersive systems, but in some schools, it is being used with intent and as an integrated part of the curriculum.

In terms of technological acceptance in this context, classroom VR studies have revealed perceived usefulness and openness to new learning methods to be significant factors (Liou et al. 2017). Prior experience of technology has also been shown to influence acceptance (Neguț et al. 2016), suggesting that the use of VR in the classroom will continue to expand, in part due to the simple fact that we as humans are increasingly growing up with the technology.

In the Workplace

The extent of VR's everydayness within workplace environments varies significantly between specific industries, but overall this particular context is where VR has become the most normalized and the technology is at its most "mature, stable [and] usable" state (Berg and Vance 2017: p.1). The entertainment market for VR has endured a volatile few decades. In contrast, VR developments in industry continued unabated, as the motivations for progress were not tied up in the consumer hype and inflated expectations that plagued the entertainment market. The result of this is that VR has been steadily improving and integrating itself as an everyday technology within industry for decades. At present, some of the most prominent applications of VR in the workplace are telecommunications, data visualization, and rapid prototyping.

Telecommunications is arguably an application of VR that could have also featured in the above discussion on VR in the home. The grand ambition of telecommunications systems is to evoke a sense of telepresence that is equal to face-to-face conversation. Coined by Minsky in 1980, telepresence originally described a feeling of "being there," experienced by individuals remotely operating robots. In a more recent definition by Ting et al. (2017), telepresence refers to "the degree of awareness of another person in an interaction and the consequent appreciation of an interpersonal relationship" (p. 382). The use of technology as a medium for communicating across great physical distances is by no means a new concept, with teleconferencing and videoconferencing systems possessing an extensive history of development and a now global usage. VR aims to bring telecommunications closer to realizing its grand ambition, with recent research projects exploring the use of VR combined with facial and body capture technology (Thies et al. 2016) and "mixed-reality telecoms," in which webcam feeds of multiple speakers are presented within a single, multiuser virtual environment (Regenbrecht et al. 2015). The potential value of VR communications is substantial across every sector of industry, enabling users to conduct presentations, seminars, board meetings, job interviews, and more, all with a quality of communication that is closer to in-person contact, but across global distances.

Early data visualizations began to appear in the early nineteenth century with bar charts, scatter plots, and line graphs (Rimland et al. 2013). Traditional (and much of contemporary) data visualization is graphics-only, two-dimensional, and static, which significantly limits our ability to comprehend complex or evolving information.

In such instances, VR has a powerful potential to overcome such limitations by way of representations that are dynamic, multidimensional, and immersive (Laha and Bowman 2012; Reda et al. 2013). As one would expect, the specific industries heavily utilizing VR for data visualization are those that deal in high volumes of complex data. These include the finance, energy, and pharmaceutical sectors (Marr 2017).

VR's ability to digitally represent architectural designs in actual scale makes it ideally suited to cost-effective prototyping, with users able to experience designs in a way that is far closer the intended final construction than a 2D image or scale model (Wolf et al. 2017). Near-future ambitions for architectural visualization largely concern three main areas: wireless connectivity, multiuser systems, and the integration of Building Information Modelling (BIM). Together, multiuser functionality and the integration of BIM data within VR enables multiple stakeholders (from architects and interior designers, to engineers and construction workers, not to mention the clients themselves) to work much more closely and collaboratively. Here, a single shared environment can present multiple facets of the design, from the aesthetics to the mathematical characteristics of the structure, all of which can be experienced within a single VR representation by everyone, all together and in real time.

Architecture is most certainly not the sole industry currently utilizing VR as a means of rapid prototyping. The ability to evaluate a product concept as a multimodal, immersive, and interactive virtual prototype has benefit to a wide range of industries including the military, aerospace, automotive, and agriculture. In many instances, the value of VR prototyping extends beyond a representation of the product, to a simulation of the real-world environment in which that product would function. This enables product development to improve various aspects of a design, from ergonomics and usability, to construction method and aesthetics (Craig et al. 2009). For those working in such sectors of industry, VR's rapidly increasing usage is making it a prominent element of their everyday working lives.

Out in the World

Everyday VR is not confined to interior applications within homes, schools, and workplaces. Rather its meaning stretches out to exterior venues and even the great outdoors. In recent years, the theatre has taken a significant interest in the potential of VR technology to both enhance and explore new approaches to dramatic performance. As Moneta (2017) points out, associations between theater and VR go back at least 20 years, where the concepts of blending physical and virtual content were initially experimented with. Moneta also points to the use of VR as a means of reimagining existing works, both to allow the initiated to experience a performance in a distinctly different way, and to make such works more accessible to newcomers. One cutting-edge example of VR-theater is *Fatherland VR* (Council 2018), a VR play in which the audience directly interact with multiple virtual characters, some manipulated by a live actor (through motion capture) with others controlled by the computer. On occasions, the way in which a single virtual character is controlled switches between human and computer control, with the audience left unaware.

Since 2015, The British Museum has been incorporating VR into their exhibitions as a means of enhancing the experience and improving educational potential (Rae and Edwards 2016). Here, smartphone VR is preferable largely due to its efficiency of use, specifically the speed at which the headset can be fitted and removed – enabling a greater number of visitors to experience the VR content throughout the day. Recent research has pointed to increased entertainment value as a significant factor in the appeal of virtual technology in museums but also points to the requirement of improved aesthetics and better social presence for VR to acquire greater technological acceptance in this context (Jung et al. 2016). As with other applications such as architectural visualization, museum VR reveals a need for further developments in multiuser systems that immerse users within virtual worlds that can be shared with others.

VR also takes things outside, presenting (for example) visitors of heritage sites the opportunity to experience "smart tourism" (see Chung et al. 2015). Here, VR software that can be downloaded directly to phones and mobile devices provides visitors with access to additional virtual information relevant to the immediate physical environment. Mobile technology, GPS navigation, and object recognition supports location-based content generation and enables visitors to hold their device towards an historic ruin and observe a digital recreation of how it once looked many centuries ago. While research and development in these technologies is ongoing, many applications of these types are already available to consumers across the world.

Lastly, healthcare is one of the most significant applications of VR technology and represents a workplace environment in which professionals are increasingly seeing VR become an everyday presence. Outside of this context, however, everyday VR also extends to healthcare for the wider population by way of its application for exercise. Here, a range of approaches are now available to consumers. These include using VR video-streaming services as a distraction during endurance cardio training and using VR action games whilst wearing body weights to enable inherently engaging activities such as playing games to also provide moderately intense workouts (Holly 2017). As individuals get older, the likelihood that they will engage with VR exercise in an everyday context becomes significantly greater. The technology is now featuring in physical rehabilitation for issues with balance, gait training, mobility, and muscular degeneration, to name a few (see Park et al. 2014; Park et al. 2015; McEwen et al. 2014).

Healthcare, in particular, reveals the benefits of there being a range of VR platforms, each with different pros and cons. For example, smartphone VR is ideal for delivering reminiscence therapy (reminiscing on past experiences as a means of preventing memory loss) as it typically involves 360° video, requiring minimal processing power, but does require greater ease of use and accessibility for both its elderly users and the practitioners delivering the therapy (Benoit et al. 2015). By comparison, physical rehabilitation favors tethered systems as it typically requires full-body tracking with 6 degrees of freedom to enable the system to evaluate the user's movements correctly. Reviews of technological acceptance are generally positive in this context, though studies have revealed that (in line with various findings in other contexts discussed earlier) improvement in ease of use and social presence (i.e., multi-user) are key to raising acceptance further (Roberts et al. 2018).

Closing Comments

To summarize, VR already presents us with new means of engaging with numerous everyday activities, from browsing the web or using film-streaming services, to family days out to museums or to the theatre. The annual workshop on Everyday Virtual Reality is now in its fourth year (Simeone et al. 2018) and is continuing to grow. Several challenges remain however. Motion sickness remains a persistent issue for many users and contemporary headsets continue to cause neck soreness and eye strain after prolonged use. The hardware is not discrete and, in social contexts, potential users remain uncomfortable with the idea of using VR technology in public. Costs remain prohibitive in many everyday contexts and in terms of usability and user experience, VR interfaces continue to lag behind more established technologies. Despite these issues, VR is already enhancing many everyday tasks and procedures that have themselves been commonplace for many decades, and in some cases, even centuries. Ultimately, it is very difficult to make predictions for the future, particularly when considering that VR technology is becoming increasingly interconnected to mixed reality, a concept arguably more compatible with everyday activities. Where VR prioritizes isolated experiences and immersion in virtual worlds, mixed reality favors the integration of virtual

worlds with our shared physical world. For everyday VR, the future is *mixed*.

Cross-References

- ▶ Cybersickness
- ▶ Mixed Reality
- ▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
- ▶ Substitutional Reality
- ▶ Virtual Reality Applications in Education
- ▶ Virtual Reality Exercise and Rehabilitation

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Evolutionary Agent Design

▶ Constructing Game Agents Through Simulated Evolution

Evolutionary Algorithms

▶ Constructing Game Agents Through Simulated Evolution

Evolutionary Computation

▶ Constructing Game Agents Through Simulated Evolution

Evolutionary Machine Learning

▶ Constructing Game Agents Through Simulated Evolution

Exercise

▶ Virtual Reality Exercise and Rehabilitation

Exergames

▶ Rehabilitation Games

Exergaming

▶ Virtual Reality Exercise and Rehabilitation

Experience

▶ Virtual Reality as New Media

Experiential Media

▶ Experiential Media: Using Machine Vision and Sensor-Input to Create Dynamic Real-Time Generated Media

Experiential Media: Using Machine Vision and Sensor-Input to Create Dynamic Real-Time Generated Media

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Synonyms

Experiential media; Interactive displays; Mixed reality; Personalized content; Reactive visuals; Real-time generated content

Definitions

Experiential media (EM) refers to models of media computing that incorporate contextual understanding of human activity, at different scales of time and space, to affect the human experience of the content through such activity. It allows user engagement by utilizing live sensors as input to a media computing unit that then outputs multimedia to output sources, such as displays or speakers. Experiential media is dynamic real-time generated media based on the live physical activity perceived with the goal of achieving enhanced and unified physical-digital experiences (Sundaram and Rikakis 2008).

Introduction

Experiential media (or EM) was used primarily by the museum industry for specialized exhibits using methods of experiential learning (Huang and Lin 2013), but has grown since then into a general tool for experiential content delivery in applications such as digital signage, architecture, hospitality, entertainment, and more. EM is often used for branding and marketing purposes among many other uses. It is growing in popularity as it allows for interactivity and higher user engagement with brands, prolonging the duration of interaction with advertising and increasing

impression counts. With the progression of intelligent computing, using methods such as Artificial Intelligence (AI), greater contextually appropriate EM is possible.

EM utilizes live sensor inputs from devices such as wearables, microphones, proximity sensors, or cameras. This entry will primarily focus on camera-based EM, using machine vision and further narrow down to focus on single camera setups. EM goes beyond classic human computer interface (Sutcliffe 1995) (HCI) as it is touchless, responsive from a distance, and its use of AI technology. It is the natural evolution of traditional audiovisual content as it gradually becomes more sophisticated and starts to become personalized to the viewer/user. EM is defined as "experiential" as it integrates user action in the design, requiring the user to physically act and move in order to experience the full media.

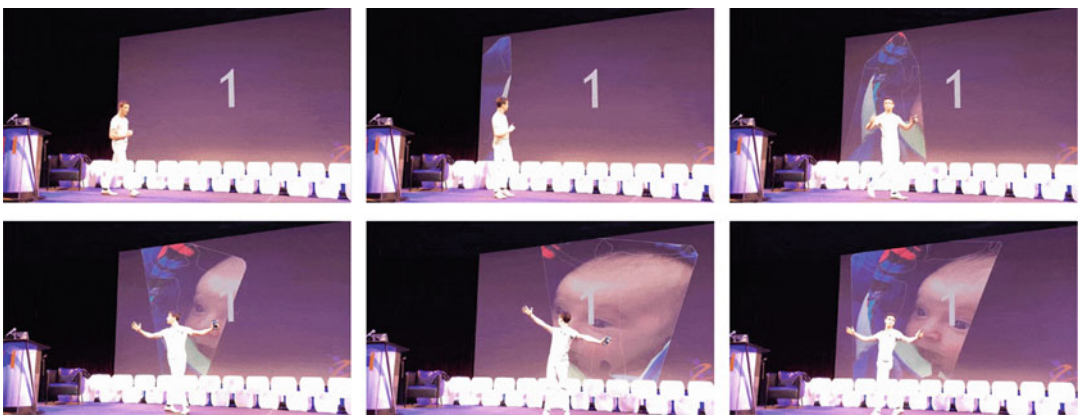
EM has the tendency to shift the user from passive viewer role to an active participant role as its elements will remain hidden or remain at their default behavior unless the user is actively moving in the intended way, as can be seen in Fig. 1. EM differs from mixed reality (Kasapakis et al. 2018) (MR) as it does not necessarily incorporate real world objects but can act as its own autonomous object. EM is presented through display mediums that are built into the environment in ways that are intended to augment or mix with the visual experience coming from physical spaces.

Uses and Frameworks of EM

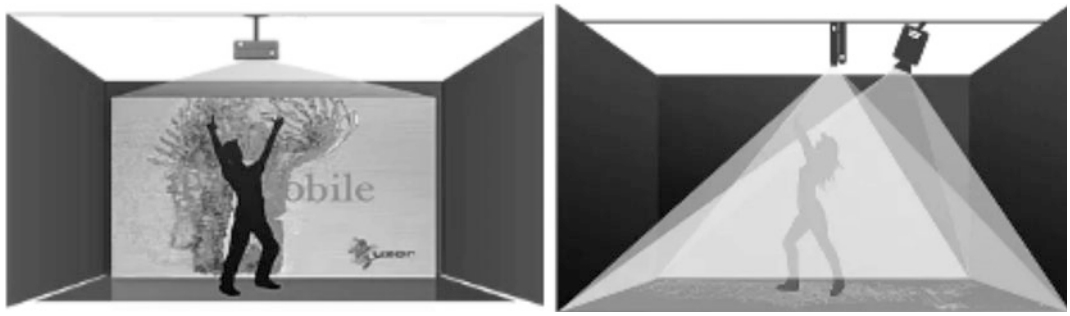
EM has multiple uses, depending on the type of content it displays, such as entertainment, educational, infotainment, wayfinding, advertising, or others. Furthermore, as large format displays become more affordable and prolific, the Digital Signage and ProAudioVisual industry are beginning to offer EM as a tool that combines content generation with immersive experiences. As of now, EM is known to be used in the following industries: hospitality, nightlife, entertainment, gaming, events, public speaking, retail, museums, and experiential marketing.

At the time of writing, the mainstream approaches to creating EM are using platforms and libraries such as Openframeworks, Unity, LumoPlay, and Zuzor. The different platforms are targeted at creators with different levels of expertise: from full coding for developers, such as Openframeworks, to creative suites that allow for rapid customization for graphic designers, such as Zuzor. There are more tools available such as Touchdesigner, Quartz Composer, etc., which are beyond the scope of this entry. A brief description of the mainstream approaches is provided below.

Openframeworks: openFrameworks is an open-source toolkit designed for creative coding written in C++ and built on top of OpenGL (openFrameworks 2020.)



Experiential Media: Using Machine Vision and Sensor-Input to Create Dynamic Real-Time Generated Media, Fig. 1 Experiential Media projected on a wall



Experiential Media: Using Machine Vision and Sensor-Input to Create Dynamic Real-Time Generated Media, Fig. 2 Upright setup (left) and top-down setup (right)

Unity: Unity is a cross-platform game engine developed by Unity Technologies that is popular for Games and Cinematics around 3D content (Unity 2020.)

LumoPlay: Lumo Play is a software solution for Windows to create games for kids using motion, gesture, and touch experiences (LUMOplay 2020.)

Zuzor: Zuzor is an Experiential-Media platform that enables the graphic design industry to easily create experiential media and the Pro-AudioVisual industry to easily deploy experiential media while tracking engagement using AI analytics (Zuzor 2020.)

Real-Time Sensing

As EM establishes a feedback loop between the audiovisual content and the user, a real-time solution to capturing the movement and context of the user is necessary. Machine vision broadly encompasses all industrial and nonindustrial applications that utilize photo detective sensors to perceive an image and utilize software to extract information from the image (Beyerer et al. 2016). The information extracted from the image is then utilized in the system's overall function. When utilizing machine vision for EM, there is a further distinction between real-time and offline usage to sense movement in a space.

EM is used in live performances, where the display medium is on stage responding to dancers or performers on stage (Performances Using Experiential Backdrops – YouTube 2020). Real time capabilities bring EM technology to entertainment with a more robust stage performance (Dubnov 2014). Previously, in many entertainment and staged environments, it was common to utilize offline approaches to create the illusion of audiovisual content as EM. While these approaches may incorporate dynamic generated media, it lacks the key real-time element that is core to this entry. The general approach was often for performers to train to move in synchrony, both temporarily and spatially, with elements of the content to make it appear as though it is interactive and contextual to their movement. This approach is prone to human error as it requires the performers to move exactly the same each time, in the exact same timing and the exact same spatial position, to create the effect of EM for the broader viewers. This approach further limits the participants to individuals that are a part of the production, as they often require numerous rehearsals, and limits an untrained individual from being able to seemingly "interact" with the system.

Machine Vision in EM

The usage of Machine Vision in EM is optimized to be perceived as instantaneous, or close to real-time, with the movement it detects. From an implementation perspective, this often incorporates software optimized to run on Graphic Processing Units (GPUs) in order to reach peak Frames Per Second (FPS). FPS is the rate at which the visual content is updated, for example, 5 fps indicates that the system updates the visual

content every 200 milliseconds. From a psychovisual perspective, a human requires visual content with a minimum of 15 FPS (Li 2009), translating to an update every 66 milliseconds, to perceive the content as continuous and smooth.

Machine vision techniques can be applied with different hardware in different scenarios to offer a range of interactions with dynamic media. Further perspective considerations are required as parts of a user's body may become obscured or no longer directly visible to the camera. From a broader framing consideration, the angle from which the camera perceives the user and the angle from which the user views the display medium need to be accounted for. Other considerations include broader viewers not interacting with the system and their perspective to the user and the display medium showing the dynamic content.

Other than the media-generation procedures that are known to use GPU, machine vision approaches are becoming increasingly optimized for GPUs. Some of the common approaches include:

Gesture tracking and recognition: tracking markers to recognize specific movements (Dubnov and Wang 2015; Wang and Dubnov, 2015)

Bodypix: a deep learning based method to extract a body contour from an rgb image (Wang and Dubnov 2015)

Human Pose Estimation: a deep learning based method to extract body joins from an rgb image (Su et al. 2020).

Setup and Hardware Options

EM constitutes multiple pieces: the sensing hardware, the display medium, and the spatial area the user is detected in. EM falls into two main setup variations as can be seen in Fig. 2, upright (left) and top-down (right). (Eye Setup 2020.) Upright configurations position the camera upright, parallel to the floor. Top-down configurations position the camera facing perpendicular to the floor, similar to a birds-eye-view looking down. The position and orientation of the camera is independent from the positioning of the display. As such, it is possible to create EM using upright activations that project on a wall directly in front of the user or activate a video wall in a different location entirely. Similarly, it is possible to create EM top-down activations that project on the floor as users move through the space or activate the ceiling or a tabletop surface.

For different setup variations, different camera types may be more appropriate. By large there are three main camera types that can be used for different variants of interactions. They are as follows:

- *IR cameras:* utilized with infrared (IR) markers that the user wears on whatever body points or objects would like to be tracked, providing the EM system with a set of (x,y) coordinates (Nawrat et al. 2013).
- *Depth cameras:* typically utilizing projected infrared mapped with structured light or stereo cameras that gives a full RGB-D (red green blue – depth) of the space, providing the EM system a full pixel map (Smisek et al. 2013).
- *RGB cameras:* the standard camera used in most laptops, security cameras, and phones, providing the EM system an rgb pixel map.

The RGB cameras are better suited if the scene is only meant to react to human movement. If the scene is meant to react to broader movement, such as moving objects or those that require a sharp contour, then the depth camera is appropriate and can be used with depth-thresholding. If the screen is only meant to react to the movement of specific objects in the space then an IR camera may be most appropriate. If the EM is designed to only react to human movement then an RGB camera with subsequent artificial intelligence (AI) methods, such as human pose estimation that can be abstracted into contours or a set of body joint coordinates (Sigal 2014), may be enough. With the top-down setup scenarios, a depth camera may be most appropriate as AI models are often not trained on birds-eye-view of humans.

Some hardware solutions may support the different variants simultaneously. One of the early

breakthroughs introducing creative coding and EM to the larger population came with the Microsoft Kinect that was released with the Xbox in 2010 (Smisek et al. 2013). At the time of this writing, a prominent provider for depth cameras, for EM and broader machine vision tasks, is Intel's RealSense (Intel® RealSense 2020) series that offers the most high resolution and physically compact solution in the market that can support any of the three variants described. The other large non-US player is Orbbec Astra that offers a depth-camera solution over usb-2 (Orbbec 2020). Of course more providers exist, but they are outside the scope of this entry.

Analytics

As EM often utilizes a camera to capture RGB, broad demographic analytics can be aggregated about the users. The measures can further be tallied against the specific experiential media displayed at the time that the metric was recorded. EM can have triggers inside the media, where a specific movement by a user can trigger the transition to a different media. As such, the use of a sequence of triggers by users can be recorded to quantify an overall map of the media a user has experienced and the overall trend on trigger activations in scenarios where multiple triggers are present.

Discussion

When designing EM, the effectiveness and impact of the interaction depends on the content design and is affected by context, such as location, the users demographics, and more. Broadly speaking, the memorability of the EM compared to traditional media is enhanced due to its multisensory nature as it involves visual, audio, and kinesthetic senses – where their combination has been shown to improve the associated memory (Ebert et al. 2009). When interacting with the EM, there is a barrier to entry for users in that they need to understand the interaction each time so that they can move appropriately. It has been observed that the amount of time it takes a user to realize an EM installation is interactive, in an unprompted environment, and the overall length of interactions the user will engage with EM depends on the users demographic. As a reference, children have been seen to engage with a single EM experience significantly longer than adults, whereas adults have been seen to have increased engagement time if the experience includes multiple triggers that allows them to transition between content quickly to explore the entire available set of EM. Depth cameras are seeing an increased demand after privacy and hygiene awareness rose and as EM offers a touchless solution, it is becoming increasingly attractive. Additionally, 3D cameras have the capability to work in very low lights and also in no-light environments like theatres and museums giving creators additional creative flexibility.

Cross-References

- ▶ Augmented Reality Entertainment: Taking Gaming Out of the Box
- ▶ Mixed Reality

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Exploring Innovative Technology: 2D Image Based Animation with the iPad

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Synonyms

2-dimensional animation; Innovative technology; iPad animation; Mobile devices

Definition

2D image based animation with the iPad is the process of developing new visualization and production methods with the use of a mobile device, while simultaneously providing theoretical and practical instruction of fundamental animation techniques.

Introduction

Teaching computer animation techniques using innovative approaches was made possible for me with two consecutive "Teaching with Technology" grants from Framingham State University. The goal of these grants is to enhance faculty competencies and improve student engagement. iPads were procured for inventive ways to learn digital animation and time-based media for artistic and commercial purposes.

In this entry, I will share how the use of technology has enriched and broadened the academic experience for students learning computer animation. I will also cover the goals and outcomes of this research, including student survey results, assessments, and animation examples. While learning to animate with iPads, students sketched ideas, brainstormed, planned narrative and storytelling structures, conducted research, and presented and shared their work. In addition, they had ongoing opportunities for collaborating with

one another on group projects, exchanging ideas, discussing work, and giving/receiving feedback.

State-of-the-Art Approaches

Complementary tactics with iPads included the studying of historical and contemporary figures in the animation field; sketching characters, scenes, and storyboards; manipulating timeline key frames and stage elements, and adjusting camera views; digitizing and editing audio tracks; and capturing and manipulating photography and video. They also digitized and edited audio tracks; and capturing and manipulating photography and video. The iPad is commonly used for *consumption*, such as watching videos and reading articles. It is not typically viewed as a tool for creating computer graphics and animation (Dowling 2012). In my project, iPads in addition to iMacs were used as tools to supplement the teaching of animation.

Summary of Work

The "Teaching with Technology" grant funding allowed me to explore new instructional approaches and inventive ways for students to learn digital animation and time-based media for artistic and commercial purposes. One objective was to minimize technical variables by utilizing identical mobile devices, so as to eliminate such problems as computer lab restrictions and lack of available software on laptops, and to encourage synchronicity. The iPads allowed students to use one primary device for learning new topics and completing projects in a timely manner, which provided the opportunity to adapt my way of teaching existing design theories to a new digital platform. They also exposed students to new concepts and helped to build their skill base with innovative tools (Davis 2012). Students were able to garner capabilities that would not be possible with the iMacs or laptops alone. The iPads also facilitated animation creation by giving students unlimited access to the same technology.

Overview of Creating 2D Animation on the iPad

The technological benefits to students were that the iPad provided them with tools to collaborate, experiment, and expand their skill set. It allowed students to develop new visualization capabilities and production methods while simultaneously providing the theoretical and practical instruction of fundamental animation techniques. It also facilitated a more imaginative process for solving problems, discovering inspiration, creating concepts, and exchanging ideas so they could more fully develop their knowledge of the subject while building more versatile computer animation capabilities. The technology that was distributed and available to students consisted of: iPads with retina display, stylus pens, protective cases with keyboards, and iPad stands. In the computer lab they had access to iMacs, Wacom digitizing tablets with stylus pens, a scanner, speakers, microphones, a large digital display, and Apple TV. Some of the apps that were provided and used on the iPads were: Adobe Ideas (vector drawing), Adobe PS Express (photo editor), Animation Creator (frame-by-frame animation), Animation Desk (high end animation), CELTX Scripts (screenwriting), CELTX Shots (storyboarding), DoInk (character animation), Flip Boom Cartoon (digital flipbook), GarageBand (audio creating, recording, and editing), iMotion (stop motion animation) and Stop Motion Studio (stop motion animation), and Storyboards (narrative storytelling).

There were advantages to teaching animation with mobile devices, which included: the minimizing of technical variables by utilizing identical mobile devices; allowing students to conduct ongoing research, write, create, record ideas, take notes, access course content, present and share work, and collaborate using one device, so as to learn new topics and complete projects in a timely manner.

Assessment tools were used to monitor what students were learning. They were beneficial as a means of informing pedagogical decisions. The following assessment tools were used: surveys at

the beginning and end of the semester, rubrics for grading project assignments, journal for understanding the learning process, and self-evaluations and critiques. Students were also asked to write in a journal every three weeks and these entries were only shared with me. Questions included: What are your initial thoughts about the course with respect to the technology provided? How has your project development evolved (i.e., research, concepts, current progress, software covered)? What are you learning, how are you learning it, and what do you want more (or less) of at this point in the semester?

Students were also given surveys to fill out at the beginning and end of the semester. Some of the final exit survey questions were: Do you use the iPad or a computer for viewing examples and animation videos, and participating in discussions? Has the iPad been an asset or a hindrance in your learning of animation? How does using an iPad for creating animation compare with the Mac?

Experiments and Examples

Projects that my students worked on and topics they experimented with included: researching animators, critical analysis presentation, storyboards and scripts for narrative storytelling, digital audio and video recording and editing, introductory logo sequences, and web banner ads, kinetic typography, character animation, stop motion animation, social cause animation (public service announcement), and photographic manipulation with iPad apps and iMac software. Examples of some of the student animations can be found on my YouTube channel: https://www.youtube.com/channel/UCepa8uuWVj5H0-19yuFUoEw (Figs. 1 and 2).

Exploring Innovative Technology: 2D Image Based Animation with the iPad, Fig. 1 Students working in Animation Studio Fall 2013

Exploring Innovative Technology: 2D Image Based Animation with the iPad, Fig. 2 Examples of student work from computer animation techniques class

Conclusion and Goals

Success when teaching with iPads included: iPads for sketching, storyboards, planning narrative sequences, conducting research, demonstrating techniques, presenting work; stylus pens for drawing and general use; student surveys; Blackboard for communication and posting course material; Dropbox & Google Drive for project submission and file storage; student interaction: exchanging ideas and assisting each other in class; apps on iPad: FlipBook, DoInk, Animation Creator, GarageBand, and iMotion.

My future goals and approaches to technology include more interaction outside of class using iPads and/or other social media approaches, inviting visiting lecturers (live or via Skype), mobile classroom both on and off campus, students demonstrate techniques to classmates on large display and/or gather in small groups, Blackboard collaborate sessions for virtual office hours, FaceTime for one-on-one assistance, eBook required in addition to web resources, voice dictation for my comments and for students posing questions, video capture for teaching how to use software (uploaded to Blackboard), sharing ideas on class blog so as to keep ongoing dialogue, group work and collaborative projects, YouTube and/or Vimeo uploads for regular online presence, social media conversations/interactions/sharing (Google Communities, Facebook, or Twitter).

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Extended Malossi Alphabet

▶ Data Gloves for Hand and Finger Motion Interactions

Extended Reality

▶ 3D Puzzle Games in Extended Reality Environments
▶ Immersive Technologies for Accessible User Experiences
▶ Virtual Reality and Robotics

Extended Reality Spectrum

▶ Artificial Reality Continuum

Eye Tracking in Virtual Reality

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Synonyms

Foveated rendering; Gaze prioritized graphics; Gaze tracking; Gaze-contingent displays

Definitions

Eye tracking techniques have many applications of research in medicine, psychology, marketing, and human factors. It is also used as a human–computer interface for applications such as gaze-based typing and communication (Majaranta 2012; Ten Kate et al. 1979), driving safety (Chen et al. 2018; Grace et al. 1998; Kutila et al. 2007; Sinha et al. 2018), and gaming (Smith and Graham 2006; Tobii Gaming n.d.). Besides being a research tool and human–computer interface in VR (virtual reality), gaze-based techniques are also used to enhance the graphics quality and performance of displays with methods of gaze prioritized graphics, also known as foveated rendering. Furthermore, statistical models of eye tracking data are employed to provide eye movements for computer-generated avatars (Gemmell et al. 2000; Seele et al. 2017; Vinayagamoorthy et al. 2004).

The human sight is limited to 135° vertically and 160° horizontally, but the detailed sense of vision occurs only within a 5° central circle which is projected to fovea centralis (or fovea), the retinal region tightly packed with color cone receptors. By detecting the movements of the eye, it is possible to distinguish its rapid movements from longer fixations to detect a person's point of regard.

There are four techniques mainly used for measuring eye movements (Duchowski 2017: 49–56). Electro-oculography (EOG) is based on sensors around the eye that measures changes on the skin conductance due to eye movements. Another technique uses scleral contact lenses that usually employ a search coil that produces electromagnetic signals. Photo-oculography (POG) and video-oculography (VOG) techniques are less invasive since they require investigation of state of the eye visually. These techniques are slightly different from the video-based combined pupil and corneal reflection, as they do not only measure eye movements, but also measure the size of the pupil and position of limbus. Unlike the other three techniques, the video-based combined pupil and corneal reflection method does not require users' head to be fixed, since it captures the

corneal reflection of a light source relative to the position of pupil. The relative positions of the corneal reflection and pupil indicate the user's gaze direction. For example, if the corneal reflection is below the pupil, the gaze direction of the user is directed above the camera (Poole and Ball 2006). The corneal reflection is usually acquired using infrared (IR) light sources. The video-based combined pupil and corneal reflection technique is broadly used in the contemporary eye tracking devices, including the VR equipment with eye tracking capabilities.

Two primary measurements used in eye tracking research are fixations and saccades. Fixations are stabilization of retina over a stationary object of interest. Saccades are rapid eye movements used in repositioning the fovea to a new location in the visual environment. These movements can be voluntary in order to switch between objects of interest. Otherwise, they can be smooth pursuits which are invoked as a corrective optokinetic or vestibular measure. The vestibular smooth pursuits occur due to the head movements of the observer while optokinetic pursuits are interspersed with saccades invoked to compensate for the retinal movement of the target. In the context of gaze-contingent system design, the identification of fixations, saccades, and smooth pursuits is a primary requirement (Duchowski 2017: 39–46).

The eye-movement based research has its historical roots in cognitive research on reading (Rayner 1998). Although the characteristics of eye movements differ across different tasks such as reading, scene perception, and visual search (Rayner 2009), the fixation of the gaze can be considered as "the top of the stack" of the cognitive processes, the focus of attention (Just and Carpenter 1976).

Duchowski (2018) categorized gaze-based interactions into four: diagnostic, active, passive, and expressive. The diagnostic methods use offline measurement of eye movements for research purposes, training, or assessment of expertise. Active methods use real-time eye tracking data as a human–computer interface for selection tasks or inputs based on gaze gestures. Passive methods utilize eye tracking in gaze-contingent displays for foveated rendering, manipulating the scene elements in response to gaze direction. The expressive use of gaze-based interactions may utilize real-time or prerecorded eye tracking data besides algorithms for synthesizing eye movements of virtual avatars.

Eye Tracking in Context of Virtual Reality

The studies considered here were selected with a focus on eye tracking applications combined with VR systems, but eye tracking studies in other fields that contribute to VR were also considered. As the VR mainly depends on 3-D (3-dimensional) virtual worlds, the methods which are integrating 3-D objects and eye tracking are mentioned, followed by a brief review of gaze-based interaction work in VR according to the taxonomy of Duchowski (2018). The scope of VR is limited to HMD (head mounted display) and CAVE (cave automatic virtual environment) systems.

Estimation of Point of Regard in Three-Dimensional Spaces

Rötting et al. (1999) used a scene camera along with the eye tracking cameras to determine the point of regard in the 3-D real world, using a two-step offline process. At the first step, at least two views from scene camera are used to detect the contours of the object in the real world to create a geometry model that approximates object in the space. At the second step, the fixations mapped on the image of the scene camera were classified on each frame that the observed model was determined. Methods used in VR reality follow a similar approach. Using HMDs, where the content is already being described by geometries, the systems could directly use the projection rendered for the particular eye from the framebuffer (Pfeiffer 2012). As the eye position to the display is fixed, the detected position of the eye on the display can be used to cast a ray into the 3-D world to detect collisions with 3-D object geometry (Duchowski et al. 2000, 2002). The methods using this geometry-based approach assume that the first object that the casted ray intersects is the point of regard. Monocular eye tracking is sufficient for

geometry-based approaches but binocular eye tracking enables detecting the vergence of the eyes to estimate fixation depth (Pfeiffer et al. 2008).

Uses of Eye Tracking in VR

Diagnostic Use and Visualization of Gaze Data

Duchowski et al. (2000) developed an HMD with eye tracking capabilities to track the users' eye movements in a virtual aircraft cargo bay training system. Their work is an early application of matching user's gaze direction on a planar surface with the polygonal 3-D virtual environment (Duchowski et al. 2002). The diagnostic use of eye tracking, such as in usability studies, require the visualization of gaze movements in forms of attentional maps (or heatmaps) that represent the density of fixations or as scanpaths that describe saccade-fixade-saccade sequences. Blascheck et al. (2017) reviewed these methods as point-based and area-of-interest based methods. Point-based methods of analyzing 3-D data were proposed for nonstereoscopic 3-D games (Ramloll et al. 2004) or real-world environments mapped into 3-D computer models (Paletta et al. 2013). Several area-of-interest-based methods are proposed for visualization of real-world eye tracking data (Baldauf et al. 2010; Itoh et al. 1998, 2000; Schulz et al. 2011; Tsang et al. 2010) with an exception of work by Duchowski et al. (2002), which is a pioneering use of eye tracking in virtual reality. The studies that include both point-based and area-of-interest-based methods provide techniques for real-world settings such as flight simulator cockpits (Weibel et al. 2012) as well as 3-D virtual environments. Stellmach et al. (2010) proposed three methods for 3-D attentional maps that are applicable to VEs (virtual environments). Projected attentional maps are 2-D planar representations of 3-D fixation data. Object-based attentional maps represent models' attractiveness by assigning a color on its whole textural surface. Surface-based attentional maps depict aggregated fixation data directly on the textural surface by attributing gaze positions on mesh triangles of models. Pfeiffer (2012) established a holistic approach to collect and visualize eye tracking data on both real-world objects and virtual environments. His method provides a volume-based modeling of visual attention. Later, Pfeiffer and Memili (2016) developed "attention textures" as a method of representing gaze fixations on 3-D objects.

Active Use of Eye Tracking in VR as a Control Interface

Mine (1995) described gaze-pointed selection among the other interaction methods. A drawback in gaze-based interfaces is the Midas touch problem, i.e., the unintentionally activated commands while the user looks at an interactive element (Jacob 1995). Tanriverdi and Jacob developed a system (2000) to compare the gaze-based interaction to point-based interaction and revealed that gaze-based interaction is efficient in a virtual environment explored via HMDs, especially to interact with distant objects. Pfeiffer (2008) with Haffegee and Barrow (2009) developed systems that employ gaze input to interact with objects in CAVE-like environments, defining a ray-casting approach to transform users' gaze into 3-D environment. Greenwald et al. (2016) manufactured a cardboard VR system with eye tracking capability for user interactions.

Gaze can be used as a "lazy" method to eliminate and minimize hand movements, as a "helping hand" to extend existing hand-based interactions, or "hand down" methods in which gaze provide a context in VR for an additional hand-held device such as a tablet computer (Zeleznik et al. 2005). Novel interaction methods can be evaluated within the context of these three classifications, e.g., duo-reticles, radial-pursuit, nod and roll (Piumsomboon et al. 2017) as "lazy" methods, or gaze + pinch (Pfeuffer et al. 2017) and VRpursuits (Khamis et al. 2018) as "helping hand" approaches.

Currently, there are several HMDs with eye tracking capabilities on the market, which provide software development kits and add-ons for different VE development platforms to transfer user's gaze direction for interacting with objects in the 3-D environment (Hollomon et al. 2017).

Passive Use of Eye Tracking in VR for Gaze Prioritized Graphics

An early suggestion to use eye tracking for rendering gaze prioritized 3-D graphics described several computational methods (Ohshima et al. 1996), but it is not clear that the proposed system is a simple prototype at proof-of-concept level or a head-mounted display with working eye tracking capabilities. Former studies (Iwamoto et al. 1994) suggested using mechanical/optical solutions for foveated rendering on HMDs. Duchowski et al. (2000) applied several algorithms to match gaze direction with polygonal 3-D objects. Those algorithms evolved into gaze prioritized rendering methods (Murphy and Duchowski 2001). The latency of eye trackers had been an issue in foveated rendering (Triesch et al. 2002), and research revealed that "foveated rendering is tolerant to eye-to-image latencies of about 50–70 ms, beyond which it is easily perceived and hence loses effectiveness" (Albert et al. 2017). Current research focuses on the comparison of different foveated rendering techniques in terms of hardware performance and user perception (Albert et al. 2017; Pohl et al. 2016; Swafford et al. 2016; Roth et al. 2016).

There are two objectives of gaze prioritized methods: increasing the rendering performance and increasing user comfort (Duchowski 2018). The speed of rendering is increased by freeing up the computational resources through matching user's "retinal and visual acuity resolutions" with the resolution of the area viewed by the user, leaving the nonfoveated areas rendered in a lower resolution. To achieve this, model- or pixel-based approaches can be followed. Model-based approaches employ polygonal simplification (Levoy and Whitaker 1990; Luebke and Erikson 1997; Luebke and Hallen 2001; Zha et al. 1999) by controlling the level of detail in polygonal objects. Current research focuses on enhancing the algorithms and optimizing the rendering field to improve the image quality perceived by users (Patney et al. 2016; Pohl et al. 2016; Roth et al. 2017; Weier et al. 2016).

The pixel-based approach focuses on spatial and temporal complexity of pixel data just prior to rendering, e.g., decreasing resolution or color depth (Watson et al. 1997). Recent research exploits this approach to vary the streaming video bit rate according to observer's gaze (Arndt and Antons 2016).

A hybrid of both object-based and pixel-based methods have also been explored (Murphy et al. 2009).

The research on increasing user comfort of stereoscopic displays utilizes gaze-contingent rendering to simulate depth of field (Kellnhofer et al. 2016; Duchowski et al. 2014). Typically, the human eyes converge and accommodate at the same point; but in 3-D displays, convergence occurs in front of or behind the screen, where the image forms while the accommodation occurs on the surface of the flat screen. This accommodation-vergence conflict often leads to a discomfort in viewers of stereoscopic displays (Mon-Williams and Wann 1998) and it is one of the reasons of cybersickness (Carnegie and Rhee 2015). To overcome this problem in VR, objects in the 3-D world that do not lie on the convergence point of user's eyes are blurred to simulate real-world depth of field.

The passive gaze-contingent techniques also employ methods that estimate the gaze movements and fixations, to overcome the latency which occurs between eye tracking and rendering (Arabadzhiyska et al. 2017; Kulshreshth and Laviola 2016). Some research focuses on employing models of estimation without using real-time eye tracking input, employing saliency maps (Advani et al. 2013; Swafford et al. 2016), or using machine learning methods to predict the important objects (Koulieris et al. 2015, 2016). Lavoué et al. (2018) compared 3-D eye tracking results and several saliency mapping algorithms and detected that algorithms still remain poor at predicting fixation locations.

Expressive Use of Eye Tracking in VR

The real-time eye movements of user captured via eye tracking, prerecorded eye tracking data, or algorithms developed to synthesize the eye movements are used to increase realism of avatars or virtual characters, as well as to increase the perceived quality of communication in a shared virtual environment. The visual deictic reference

enslaved to users' gaze found to be enhancing the trainee performance in collaborative VEs using HMDs (Duchowski et al. 2004; Sadasivan et al. 2005). In a multiparty object-focused puzzle scenario conducted on a CAVE-like environment (Steptoe et al. 2009), the tracked gaze was observed as the highest performing condition. Murray et al. (2009) implemented an avatar-based video conferencing for CAVE-like VR systems that supports eye tracking and they evaluated the role of gaze in remote communication. Recently, Roberts et al. (2015) implemented an eye tracker in their end-to-end telepresence system.

Duchowski (2018) criticized the method of mapping prerecorded eye movements to a virtual character as it is costly since this method requires an actor for every recording while eye tracking devices inject noise to eye movement data during recording. Alternatively, synthetic eye movements are employed in development of virtual characters and humanistic robots, which involve modeling saccades, smooth pursuits, binocular rotations implicated in vergence, coupling of eye and head rotations, pupil dilations and constrictions, and microsaccadic jitters during fixations (Duchowski and Jörg 2016).

Cross-References

- ▶ Foundations of Interaction in the Virtual Reality Medium
- ▶ Perceptual Illusions and Distortions in Virtual Reality
- ▶ Spatial Perception in Virtual Environments
- ▶ Virtual Hand Metaphor in Virtual Reality
- ▶ Virtual Pointing Metaphor in Virtual Reality
- ▶ Virtual Reality Game Engines
- ▶ Virtual Reality System Fidelity

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Face Beautification in Antiage

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Synonyms

Face makeup; Face skin and shape beautification; Reversed face beautification

Definition

Face beautification in antiage is a technology of making human face beautiful based on the reversed aging revolution, which means that the algorithm produces a more beautiful face by changing the texture and shape of the original human face.

Introduction

Face beautification is an essential research topic in the image process and computer graphics, which contains dozens of algorithms based on 2D or 3D human faces. The process of 2D image is generally divided into two directions. Furthermore, the main idea of beautification method is to smooth textures by using the special filter and to change the geometry of face shapes by using designed warped projections. The rise of the 3D print technology promotes the development of the beautification methods of 3D scans, most of which concentrate on face shape beautification. Due to the great effect that it has in feature extraction and expression, deep learning improves the results of beautification by matching the features of input faces to the attractive ones based on the theory that faces combined with the good features of beautiful faces have the perfect appearance. Currently, numerous companies focus on accelerating the research and development of human face beautification applications.

There is a widespread knowledge that the younger face with less wrinkles is more attractive. Face makeup is one of the most effective methods to enhance a person's appearance, which can also make the face younger. Furthermore, medical technologies have developed rapidly; thus, an increasing number of people have cosmetic surgery to achieve the younger effect. Although a number of celebrities benefit from it, many people failed due to the high risk of the surgery. It is worth for some people to take the risk, while it is not necessary for most of other people. But we cannot deny that everyone would like to be more beautiful on photos. As technology progresses, it is convenient for people to increase the quality of photos by using image post-processing technology. Face beautification in antiage attracts growing attention in the image processing field, which generates numerous algorithms.

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In this entry, we do a survey and introduce the present work in face aging, aesthetic plastic technology, and reversed age face beautification.

State-of-the-Art Work

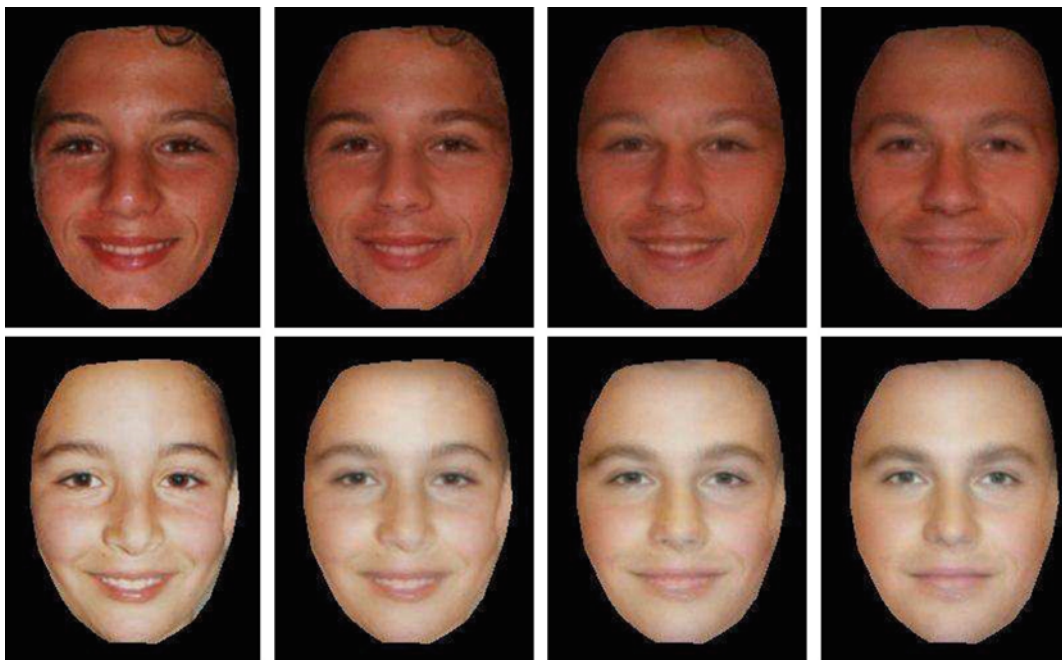
Many researchers have been exploring in the image processing field, and they constantly improve face beautification algorithms based on the face aging rule. Firstly, we introduce the present face aging algorithms, which are related to the face beautification methods. Secondly, we briefly survey the plastic technology to explore the mysteries of facial aesthetics. Finally, we discuss the reversed age face beautification algorithms (Fig. 1).

Face Aging

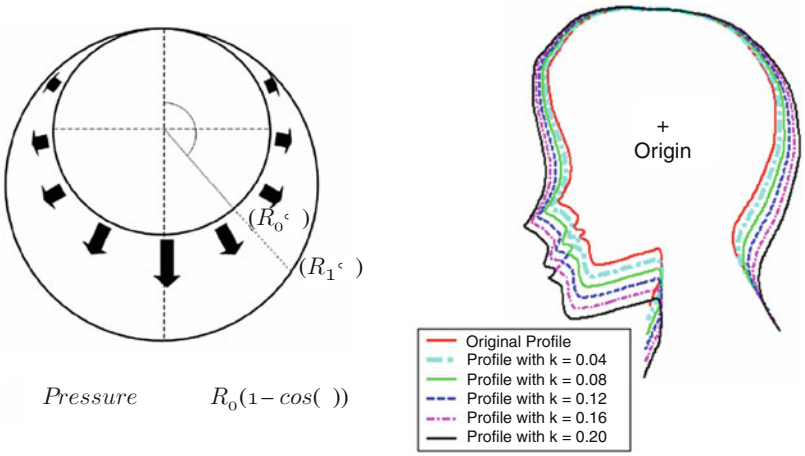
Facial aging algorithm is mainly used in cross-age face recognition, entertainment, and other fields. The main idea of the algorithm is to add age features to the young faces without changing the identity characteristics. Traditional methods, respectively, change face textures and shape (Ramanathan and Chellappa 2006; Kemelmachershlizerman et al. 2014; Shu et al. 2015). In 2016, Wang proposed recurrent face aging (RFA) framework based on RNN to generate the aging face which produced more natural results (Wang et al. 2016). However, this method can only generate younger face stage by stage, which cannot produce older faces across the stage. Generally, the human face aging process has close relationship to wrinkles and shapes (Fig. 2).

Aesthetic Plastic Technology

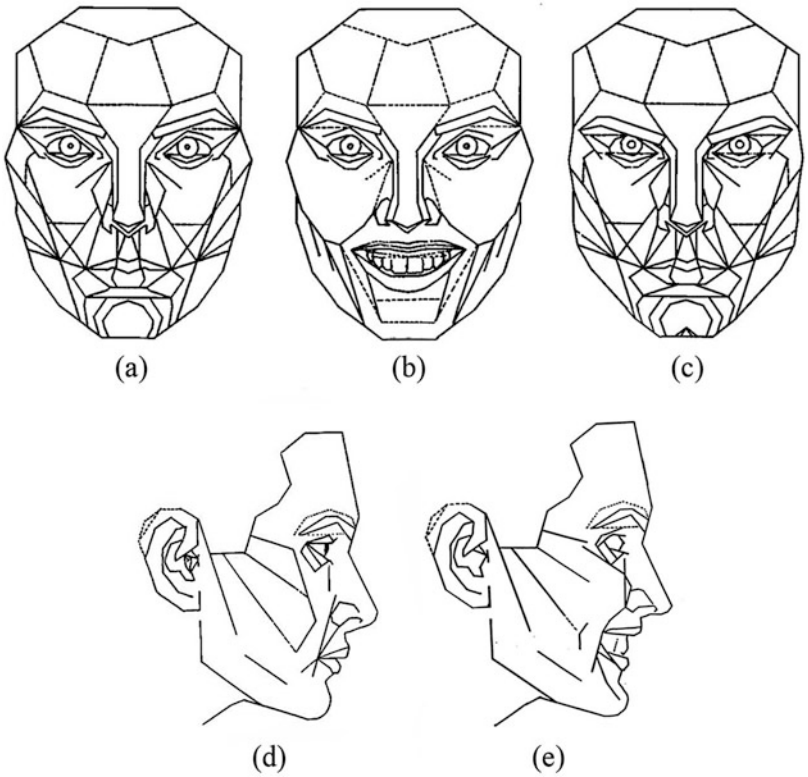
With the improvement of medical technology, people can change their face texture and shape to make a younger and more charming face by having aesthetic plastic surgery. In 1962, Gonzalez-Ulloa M put forward the principle of aesthetic plastic (Gonzalez-Ulloa 1962). Therefore, cosmetic technology has been receiving increasing attention. A large amount of cosmetic methods have been proposed, such as antiaging plastic



Face Beautification in Antiage, Fig. 1 The face aging examples from teenagers to adults (Ramanathan and Chellappa 2006)



Face Beautification in Antiage, Fig. 2 The skull model (Todd et al. 1980)



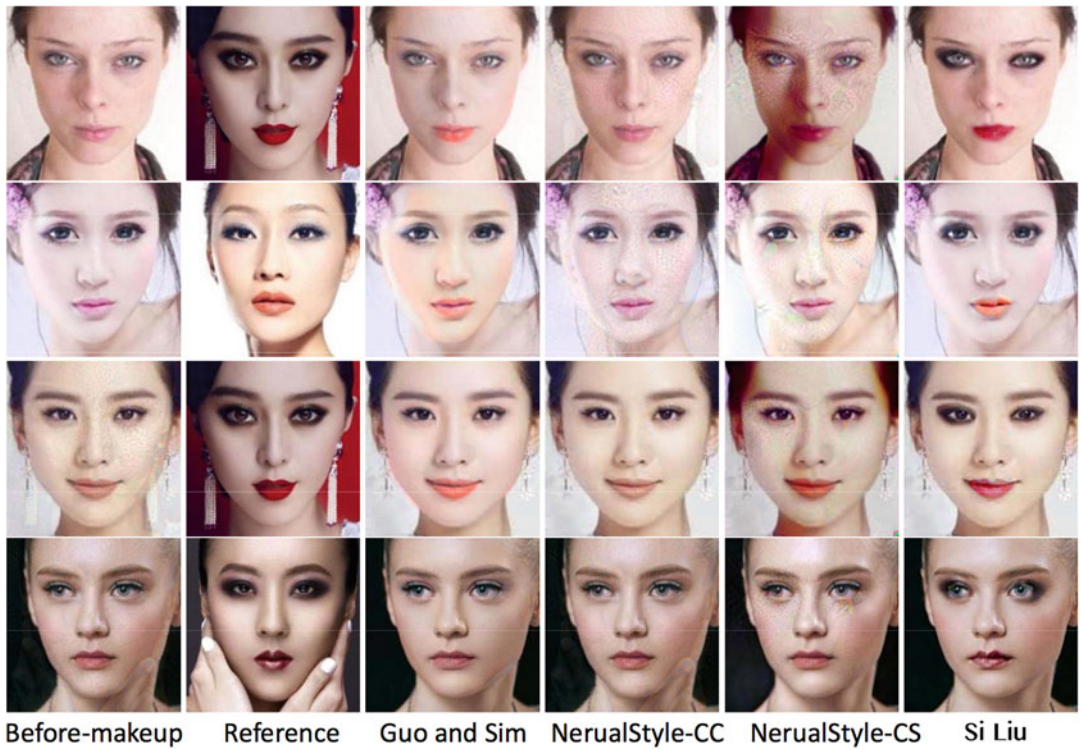
Face Beautification in Antiage, Fig. 3 The Marquardt mask (Stephen 1997)

surgery (Giampapa et al. 2003), double eyelid surgery (Song and Song 1985), etc. What's more, Brennan proposed a method to beautify the skin (Brennan 2015). There are dozens of specific methods to make you look more beautiful. Some of these patients would like to have a more symmetrical face. As mentioned above, Liu Fang did the research and showed that the symmetrical face is more charming (Liu 2010). Thus, morphing the face toward symmetry properly can improve the face' attractiveness. But this is only one general rule, while there are also some

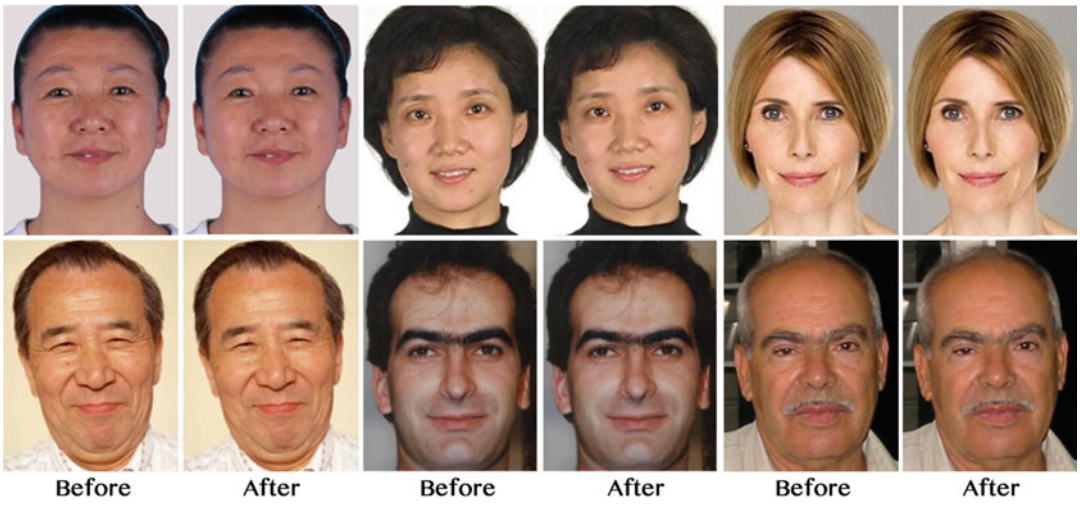
asymmetric faces which are more beautiful. Others who aim to change the shape of their face usually choose an attractive star as the target or look for a generally accepted face. At this time, most of the doctors would choose the Marquardt mask, which is the standard face of the aesthetics. The Marquardt mask is also called the golden face for that it conforms to the golden ratio. When the person who is older than 20 years old grows up, the face shape would go far from the Marquardt mask, which also means that the face aging has great effect on the attractiveness of human faces (Fig. 3).

Reversed Age Face Beautification

In recent years, face beautification in antiage algorithm has made unprecedented progress in the image processing field. Face texture is affected by five characters, such as spots, wrinkles, puffiness, dark circles, and shapes. In the real world, people change these characters by using cosmetics, while there are corresponding algorithms in image processing area. There are lots of company proposing the applications to achieve the demand of consumers, such as Microsoft, Facebook, Apple, Tencent, etc. Other algorithms are presented to learn the age features and apply the reversed aging features directly to beautify human faces. In 2013, Chen use standard deviation to extract the age feature and get younger face by training SVM (Chen et al. 2013). In 2015, Sun proposed a method to replace the aging skin with neighbor skin with younger features, which produce younger faces without losing the identical features (Sun et al. 2015). Deep learning developed rapidly which promotes the development of the skin texture beautification. In 2015, Li learns the features which are related to beautification by using deep learning to generate beautified faces (Li et al. 2015). In 2016, Xi Lu proposed a framework focused on skin beautification based on layer dictionary, which is good at removing facial



Face Beautification in Antiage, Fig. 4 Face makeup examples (Liu et al. 2016)



Face Beautification in Antiage, Fig. 5 Face beautification examples (Sun et al. 2015)

wrinkles and spots (Xi Lu et al. 2016). These algorithms focus on different aspects and have achieved great results (Figs. 4 and 5).

Conclusion and Discussion

Facial beautification algorithm develops rapidly; there are many companies that invested a great deal of resources for in-depth study. A variety of face beautification algorithms are proposed recently. Increasingly importance has been attached to the face beautification method in antiage since it protects the personality of human faces in the beautification process. There are many applications that can beautify face in real time, but these algorithms still have to be improved, such as promoting the sense of reality and removing the age characteristics. Face beautification algorithm in antiage would have great development in the future.

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Face Detection

▶ Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces

Face Makeup

▶ Face Beautification in Antiage

Face Recognition

▶ Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces

Face Skin and Shape Beautification

▶ Face Beautification in Antiage

Facial Recognition

▶ Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications

Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications

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Synonyms

Emotion detection; Facial recognition; Image processing; New media art work; Vision system

Definition

Real-time detection and analysis of facial recognition and emotion states is a technique that offers methods and processes for the control of media content, communication via interactive experiences and social media.

Introduction

Facial recognition technology is a growing area of interest, where researchers are using these new applications for study in psychology, marketing and product testing and other areas. There are also applications where the use of facial image capture and analysis can be used to create new methods for control, mediation, and integration of personalized information into web based, mobile apps, and stand-alone systems for media content interaction. Our work explores the application of facial recognition with emotion detection, to create experiences within these domains. For mobile

media applications, personalized experiences can be layered personal communication. Our current software implementation can detect smiles, sadness, frowns, disgust, confusion, and anger (Database FERET). In a mobile media environment, content on a device can be altered to create fun, interactive experiences, which are responsive and intelligent. By intersecting via direct communication between peer to peer mobile apps, moods can be instantly conveyed to friends and family – when desired by the individual. This creates a more personalized social media experience. Connections can be created with varying levels of intimacy from family members to close friends out to acquaintances and further to broader groups as well. This technique currently uses pattern recognition to identify shapes within an image field using a Viola and Jones (2001) Haar-like feature detector, OpenCV (Bradski and Kaehler 2008), a "Feret" database (Chang and Lin) of facial images, and a support vector machine library (LibSVM)(Burges 1998; Bolme 2003) to process video or images from a web camera and to identify if a face exists. The system processes the detected faces using an elastic bunch graph matching (Hlang 2012) technique that is trained to determine facial expressions. These facial expressions are graphed on a sliding scale to match the distance from a target emotion graph, thus giving an approximate determination of the user's mood.

State-of-the-Art Work

Currently, many media artists are using vision systems, sensor-based systems, and other technologies to create interactive experiences and mediated arts works in public spaces. In many of these works, the images are projected onto building facades or use embedded LED arrays on building surfaces. In Asia, it is common for newer buildings to use vast LED arrays on the façade of the building. These projections and LED arrays can use video playback, images changing over time or other ways to control the imagery. Our work focuses on the possible use of vision systems for the face detection and facial recognition, which then can be used to control or mediate visual information on surfaces in public spaces or to allow mobile apps and web-based experiences and through social media.

Overview

Considering historical examples, artists have explored the use of projected imagery or light works as a primary medium. These works may fall into one or more genre or may be in between different genres of art. Looking at examples of installation, or environmental art works, the work of Dan Flavin (https://chinati.org/collection/danflavin.php) is exemplary in the use of light as a singular imaging medium. Flavin's work, as he has described it, is created and experienced in a strict formalist approach. Formalism focuses on the way objects are made and their purely visual aspects. Nevertheless, the works, such as Flavin's, though static light alter or inform audience spatial perception of spaces where they are installed. In our study of the use of interactive elements, can the viewer's perception be altered by the shifting of color or imagery based on responses detected from the viewers themselves? Further, can we use the detection of subtle emotional cues to alter the qualities of the imagery or installation? More recently, the projection of video or animated imagery on building facades or in public spaces has become a common way to attract viewer engagement. In these types of new media art work experiences, such as the 2011 transformed façade of St. Patrick Cathedral and the New Museum in New York (http://www.newmuseum.org/ideascity/view/flash-light-mulberry-street-installations, these altered architectural and public spaces become a "canvas" where images and media content can be viewed outside of the special circumstance of the gallery or museum. Considering possible ways to allow for audience interaction, we know that sensors and vision systems are being used to encourage audience participation. Can subtle emotional cues be used as well?

Facial Recognition for Artistic, Environmental Installation in public Space

Detection of emotion states in a public art installation to change the environmental elements is possible. Using webcams positioned in specific selected locations can capture facial information, the emotion states can be detected. The detected state can be used to alter projected imagery, auditory ambiance and ambiance of lighting, intensity and color. The location of the camera need not be directly within the installation space. Indeed, the control of the qualities of the imagery, lighting, or ambiance can be collected remotely in other building location, from the Internet and even by mobile apps (Fig. 1).

In my work, "MoodModArt," and the subsequent system "MoodRing," we use emotion detection to change the quality of an image based on detected moods (Fig. 2). "In MoodModArt," detection of the seven basic emotions states (Ekman 1999) enables responses in the imagery as a results of the emotion detected. The seven basic emotion states as defined by Eckman are the states used for training and detection in "MoodRing."

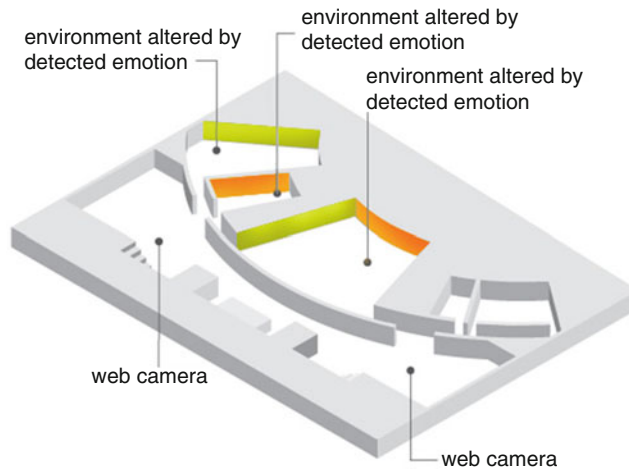
If the detected emotion of a viewer is positive, the streamed loop of video is vibrant and colorful. If the detected emotion is negative, the streamed loop of video played to a drab and darker view. The viewer can change quality of the image by altering their facial expression Fig. 3.

Facial Recognition in Mobile Apps, Internet Webpage Detection, and Stand-Alone Kiosk Systems

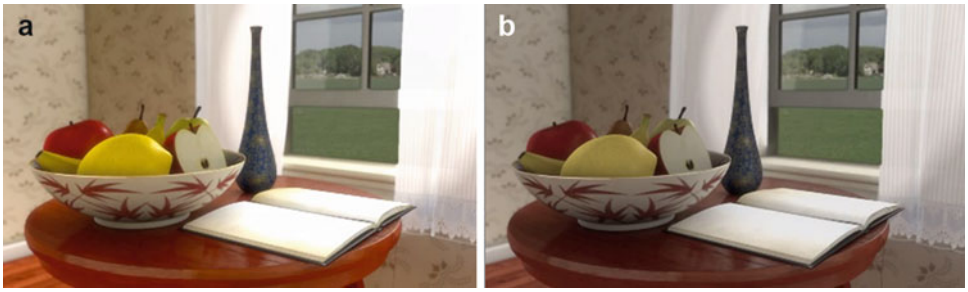
In mobile apps, detected emotions of a viewer can be shared via social media through simple #hashtag or Facebook posts. Using HTML5/CSS3 along with Canvas, apps, and webpages can be used to capture and submit an image to a back-end server application, which returns a detected emotion state. Apps and webpages submit an image to a cloud database. The server listener application listens for images arriving, tagged with random user IDs and time stamps. The listener passes the image to a back-end server application, which returns a detected emotion state to the listener. The listener then returns the result to the webpage or app (Fig. 4).

Developmental Work in Facial Recognition: Gender and Age

Our work in facial recognition began with experimentation with the detection of gender and age in public spaces. In our earlier project "HiPOP," we were successful in implementing a software tool for facial recognition for use in public spaces. The

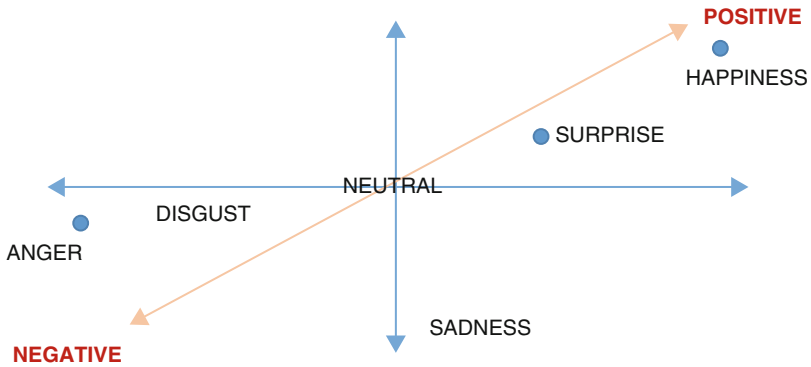


Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 1 A schematic view of a museum with capture location and installation spaces



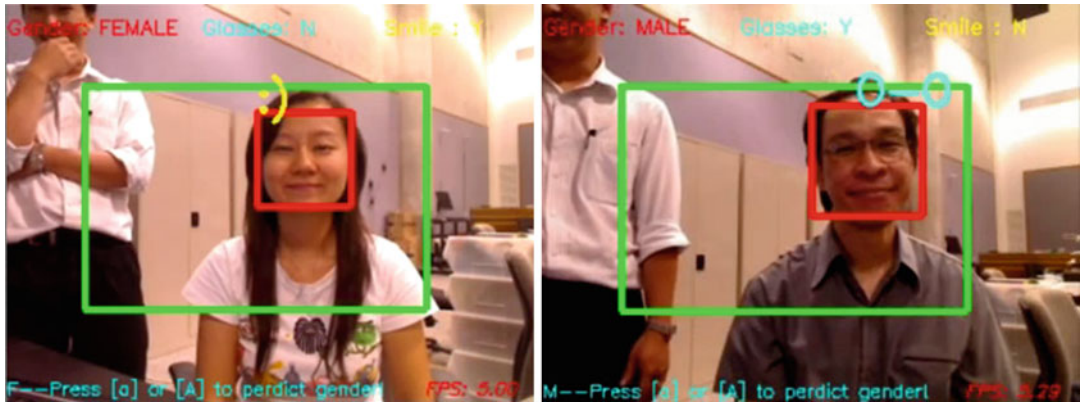
Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 2 (**a**, **b**) Images from the looped media streams in MoodModArt

Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 3 Graphing of emotion states on a continuum from negative to positive



Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 4 Transfer of captured images to a server application and the return of a detected emotion

focus of this work revolved around the detection of gender and age. This implementation uses an image processing approach by identifying shapes within an image field using methods published by Viola and Jones (2001). The technique employed a Haar-like features application (Viola and Jones 2001; Burges 1998) and a "Feret" database (http://www.nist.gov/humanid/colorferet; Chang and Lin) of facial images. A support vector machine (LibSVM) (Burges 1998) was used to classify the faces to glean attributes such as gender, age, and other individual characteristics. The system segmented the captured image to recognize face rectangles. The detected face area is scaled to a



Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 5 Detected genders invoke playback of targeted media

64 × 64 pixel grayscale image and an equalized histogram is used to increase contrast. The OpenCV (Bradski and Kaehler 2008) library was used to detect and segment faces from video images through the following methods:

1. Using a cascade of boosted classifiers working with Haar-like features.
2. Training classifiers by a database of face and nonface images.
3. Scanning input images at different scales to find regions that are likely to contain faces.
4. A SVM classifier method using data points as a p-dimensional vector was used to detect smiles in the captured images, where p is the number of feature pixels in the image.

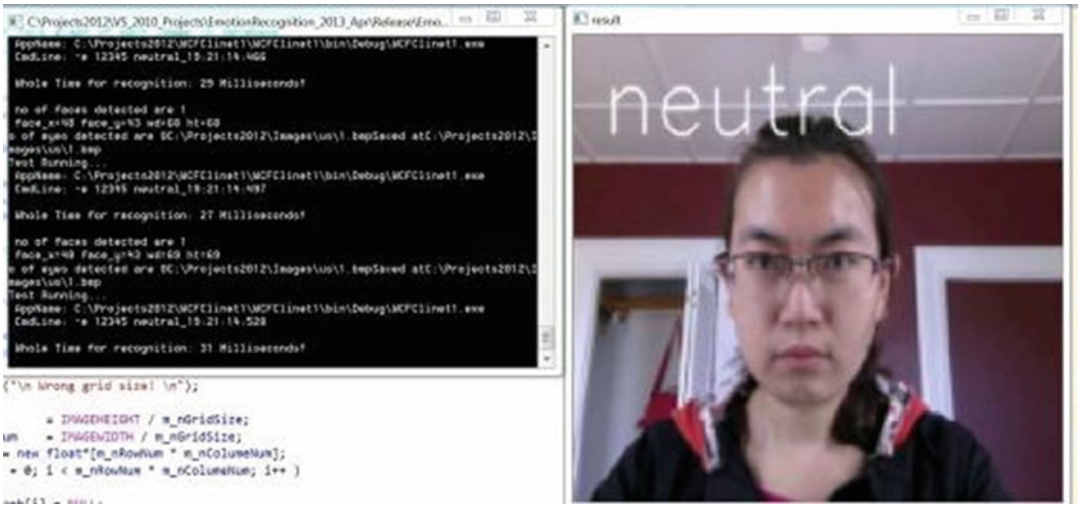
Application of such a system is feasible in environments where marketing messages can be targeted for individuals based on gender, age, or other cues that can be identified. The design of the system installation allows marketing or media content to be played based on the detection of certain demographic information detected from consumers in a retail environment (Fig. 5).

Development of Emotion Detection: Emota v1.0

Work on emotion detection in the initial stages used a hybrid approach with a library of images, each with an elastic bunch graph match (EBGM) (Wiskott et al. 1997; Hlang 2012). The software implementation was designed with two modules to process the captured video images and give the resulting detected emotion. The "ImageNormalizer" module detected the face from an image, cropped, resized to a standard size (90 × 100 pixels), and converted these to grayscale. The normalized image was input to the EBGM program. Training for detection of emotion states in an individual was required for accuracy. The technique used a database of filtered images defined with an index set that were identified as one of seven emotion states. The "EmotionRecognition" module integrated with "ImageNormalizer" so that every captured frame was normalized and the detected face was stored in normalized form on the fly. "EmotionRecognition" used EBGM with the on the fly normalization program to output a detected emotion state from the captured image (Fig. 6).

Development of Emotion Detection: Emota v2.0 (Mood Ring)

Additional work in the detection of emotion has continued with the version 2.0, entitled "MoodRing." This implementation has four modules: MoodRing MFC, MoodRing Core, Weight Trainer, and Database Compressor.



Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 6 A screen capture of Emota v1.0 in action

Both MoodRing MFC and MoodRing Core are implementations of the project's core part. MoodRing Core is the interface version which shows how to set up this project under different platforms. Weight Trainer is used to train weight of each anchor point to calculate similarity among subgraphs. Once a model is trained, elastic bunching graphs (Wiskott et al. 1997; Hlang 2012) can be stored and compared instead of images. Database Compressor is used to compress elastic bunching graphs by comparing, searching, and combing similar graphs based on the distance among them.

MoodRing MFC is a stand-alone MFC version which supports emotion storage, batch training, and emotion detection. There are two options for emotion storage: user emotion storage and batch emotion storage. Batch emotion storage allows user to parse batch amount of images to xml files and add these files to dataset of certain user. The batch module is designed mainly to train large amount of images in order to set up the default dataset which belongs to the default user (Fig. 7).

User emotion storage allows user to capture, extract, and store emotions to numeric values one by one using a web camera. To use this system, the user initiates the training and capture of emotion state facial expressions by instantiating "user emotion storage." The system prompts for the seven emotion state expressions, and the images are captured and accepted. Once the seven states are stored, the system is effectively trained for that user (Fig. 8).

User emotion detection allows real-time user emotion detection. This can be used as a control for interaction, media, and environmental elements.

Emota v2.0 Mood Ring Core and Data Processor

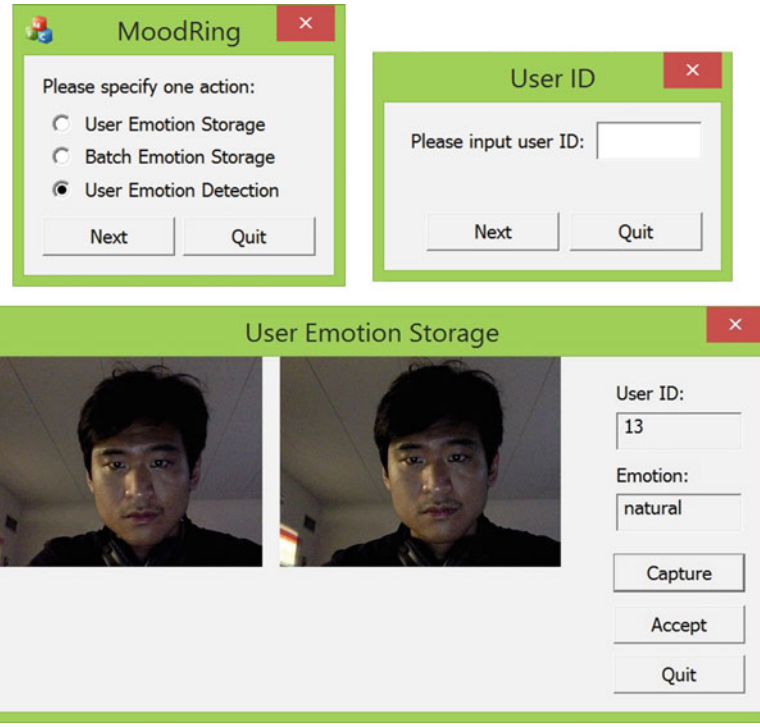
Image Preprocessing

First, we apply some image standardizations to get a small size gray scale image. Second, a series of image preprocessing operations are adopted, including noise removal and image balance.

Noise Removal (Ester et al. 1996). For each pixel, we calculate and accumulate the difference of all its neighbor points as the weight of this pixel:

$$\text{weight}(\text{x}) = K_1 e^{-K_2 \sum_{p \subset \text{P}} |f(p) - f(\text{x})|}$$

where P is the neighbor point set of pixel x, and f (x) is the pixel value of x.



Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 7 The interface windows for operation of MoodRing MFC

Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 8 Detected emotion states are stored in a periodic manner to a text file that is readable by other software, such as Max/MSP

Then, we traverse the image again with a weighted average filter for each pixel.

$$g(\mathrm{x}) = \alpha \frac{\sum_{p \subset \mathrm{P}} \mathrm{weight}(p) \cdot f(p)}{\sum_{p \subset \mathrm{P}} \mathrm{weight}(p)} + (1-\alpha) \cdot f(\mathrm{x})$$

Image Balance. We have noticed that vague shadow will not heavily affect Haar classifier performance, and hard shadow edges can heavily weaken performance. An image balance method is adopted such that useful information like edges is strengthened while noise like shadows is weakened. Thus, instead of complex shadow removal

algorithm, we adopt following operations to concentrate effective image information so that Haar classifiers can find target more easily:

$$f(\mathrm{x}) = \begin{cases} \alpha K \log(\mathrm{x}) + (1-\alpha)\mathrm{x} & , if\ \mathrm{x} < 127 \\ \alpha[255 - K\log(\mathrm{x})] + (1-\alpha)\mathrm{x} & , if\ \mathrm{x} \geq 127 \end{cases}$$

Face Detection

After above operations, we adopt a set of pretrained Haar classifiers (Wang et al. 2007) to locate only one pair of eyes and mouth (Alpers 2011; Messom and Barczak 2009). For facial detection, only eyes and mouth are used in this case. If multiple rectangles are found for the same part, we run a clustering method to estimate the target rectangle based on the Euclidean distance. We run a clustering algorithm based on Euclidean distance between locations of each possible candidate.

For example, to find one's left eye in all possible locations, say A, B, C, and D:

1. First, these possible eyes are clustered based on their locations and distance to each other. (A, B, and C are on the left side, while D is on the right side; A is near to B, while C is far from them. Then, we have {A, B}, {C}, and {D}.)
2. Then, clusters are selected based on their size and location with another eye. (If {A, B} are at similar vertical location as {D}, and symmetric to centerline of face about {D}, we choose {A, B} as left eye and {D} as right eye.)
3. Finally, location and size are calculated using {A, B} and {D}.

Then, a set of anchor points can be delivered based on these rectangles. Before feature extraction, lumen normalization is adopted to detected facial part of the image such that light conditions have less effect to the feature extraction process.

Feature Extraction

Numeric features are extracted through convolutions with a set of precalculated Gabor filters called Gabor Bank.

Gabor Bank

Gabor filters are implemented to derive orientations of features in the captured image using pattern analysis, directionality distribution of the features. Using Gabor filters increases accuracy of the anchor points derived in the elastic bunch graph matching. Gabor filters of all scales and orientations compose the Gabor Bank to detect edges and textures. In the Gabor filters:

$$\begin{aligned} g(\mathrm{x},y) &= \frac{k^2}{\sigma^2}\cdot e^{-\frac{k^2(\mathrm{x}^2+y^2)}{2\sigma^2}} \\ &\quad \cdot \left(e^{ik\begin{bmatrix}\mathrm{x}\\ y\end{bmatrix}} - e^{\frac{\sigma^2}{2}} \right), \text{where}\, k \\ &= [k_v\cos\varphi k_v \sin\varphi], k_v = 2^{-\frac{v+2}{2}}\pi \end{aligned}$$

where σ is the standard deviation of Gaussian envelope, φ is the direction of Gabor stripes, and v determines the wavelength of Gabor filters.

We choose 18 Gabor filters with six directions and three phases to compose a Gabor Bank.

Directions include:

$$\left|0, \frac{1}{6}\pi, \frac{1}{3}\pi, \frac{1}{2}\pi, \frac{2}{3}\pi, \frac{5}{6}\pi;\right.$$

phases include:

$$\left.C\pi, C\sqrt{2\pi}, C\sqrt{3\pi}\right|,$$

where C is a constant. Such a Gabor Bank will be initialized when the program starts, and used every time extracting features.

Elastic Bunch Graph

Operations of elastic bunching graph include graph matching, graph pruning, and adding subgraphs from either an image or an xml file. Elastic bunching graphs apply convolutions of certain areas of images using all filters in the Gabor Bank. This results in a list of anchor information for all anchor points, where each anchor information contains a list of all convolution results corresponding to filters in the Gabor Bank. If the

program is in a training mode, it will store the hierarchical results as an xml file. Otherwise, emotion detection is followed after feature extraction.

Graph pruning is the core function of Database Compressor. The pruning algorithm is basically a variety of DBSCAN (Ester et al. 1996), where the distance of subgraphs defined as sum of Euclidean distance of all convolution results for all anchor points. If one cluster contains at least the minimum number of neighbor point subgraphs, and distances of these subgraphs are at most eps, we combine all subgraphs in one cluster into one. Thus, very similar subgraphs are merged to reduce storage space and comparing time. Emotion Detection.

The emotion detection is a similarity comparing process. Target graph is compared with all subgraphs in all seven emotions (Database FERET) in the FERET dataset. We categorize the target graph for the same emotion type as its most similar subgraph. In comparison of two graphs, we can calculate a weighted average on the distance of all such convolution results of all anchors in graphs. When the program is initialized, a mathematical model determined by Weight Trainer is loaded, such that the weight of each anchor can be used to measure graph similarity (Fig. 9).

There are two types of preloaded dataset used in the detection process: default graph set and user graph set. When initialized, the program will load the default graph set, which only contains graph of the default user. As mentioned above, dataset for the default user is usually trained in the Batch Emotion Storage module. Since default user's dataset contains large amount of samples from existing database like "Feret" (http://www.nist.gov/humanid/colorferet, it can be used without user graph set. However, user graph set is still a better choice because it contains fewer but more informative graphs. Based on given user ID, the program will load graphs of that user into user graph set if program can find user emotion data of this user. Otherwise, only the default graph set will be loaded.

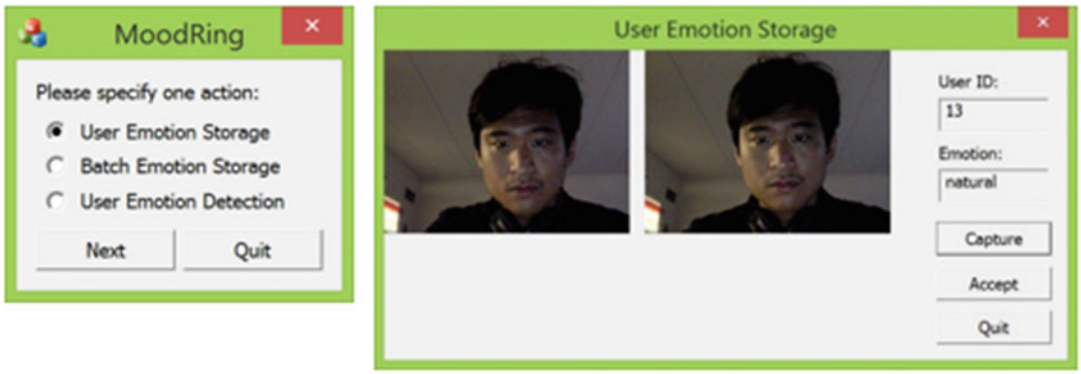
Weight Trainer

Weight Trainer is the first step to set up the MoodRing system. Input of this module is a set of elastic bunching graphs with all seven emotions; output is a weight matrix stored as local file.

Given a set of seven graphs, G_i (i = 0, 1, 2, 3, 4, 5, or 6), and each graph G_i has subgraphs g_{ij}, we first generate the dataset through a pairwise comparison:

$$\begin{aligned} x &= g_{ij} - g_{mn}, y \\ &= \begin{cases} 0, & \text{if } i = m \text{ (same emotion)} \\ 1, & \text{if } i \neq m \text{ (different emotion)} \end{cases} \end{aligned}$$

Then, because y is between 0 and 1, we apply the following logistic function on X:



Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications, Fig. 9 Training if the EmotionDetector

$$\text{Input matrix}: g(\mathrm{X}), \text{where x} \subset \mathrm{X}, \text{and} g(\mathrm{x}) = \frac{1}{1+e^{-t}}$$

$$\text{Output matrix}: Y, \text{where} y \subset Y,$$

Now that we have transferred the dataset into this form, we adopt certain classification methods, like LibSVM (Bolme 2003) to train the weight matrix. If size of X is small (e.g., for individual users), we will use batch training; if size of X is large (e.g., for the default user), we will use mini-batch stochastic training instead. The boundary of these algorithms is a constant value. Boundary p″ in this case means:

> For given testing sample g_{ij} and dataset sample g_{mn}, we can calculate the estimated $\hat{y}$ value using the trained model. If $\hat{y} \geq p$, we can conclude g_{ij} and g_{mn} are the same emotion type; otherwise, they are different.

Future Work

- Application of the detection is feasible in installation and environments, and public spaces.
- Further experimentation is necessary to determine accuracy of the facial capture and emotion detection.
- Further work will include continued refinement of the image processing and normalization to operate in varying lighting conditions.
- Mobile app and social media application exploration will continue.
- Experimentation and comparison of image library-based implementations and EBGM for the further development of a "universal" detector.

Cross-References

- ▶ Cognitive Psychology Applied to User Experience in Video Games
- ▶ Emotion-based 3D CG Character Behaviors
- ▶ Modeling and Mesh Processing for Games
- ▶ Vector Graphics

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Fall Risk Detection in Computer Vision

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Synonyms

Anomaly detection; Computer vision; Fall risks; Machine learning; Pose estimation

Definition

Anomaly Detection
Anomaly detection identifies unexpected items or events in data sets from the norm.

Fall Risks
Fall risks are common threats affecting all individuals, including the elderly or young children.

Computer Vision
Computer vision is an Artificial Intelligence (AI) system incorporated with other scientific fields, such as signal processing and neurobiology, to interpret and gain a high-level understanding of digital images or videos.

Machine Learning
Machine learning employs software tools from advanced analytics that use statistical algorithms to find patterns in datasets. Machine learning algorithms have two categories: (1) Supervised learning: The data is labeled and trained according to various classes, such as malicious and legitimate, to form mathematical models for the algorithms. Next, (2) unsupervised learning: The data is not labeled or trained. However, the algorithms determine the degree of data coherence to create classes according to the quality of data coherence within the classes and data modularity between them.

Pose Estimation
Pose estimation is a computer vision technique used for identifying human postures.

Motivation and Background

Fall risk is a common occurrence threatening individuals of all ages, from young to older adults. Typically, older adults are at a higher risk of falling. Poor eyesight, poor balance, and medication that causes drowsiness can cause severe harm and danger. Researchers continuously investigate evidence-based strategies to prevent falls, examine contributing factors like human behavior, and implement advanced technologies to monitor an individual's balance and movement.

Related Works

Previous studies on fall detection can be classified into two main groups: vision-based and sensor-based methods.

Sensor-based methods can be further divided into wearable-based and ambient fusion-based methods. Wearable-based methods mostly employ accelerometers and gyroscopes, and combining multiple sensors can improve their accuracy (Wu et al. 2012). In contrast, ambient fusion-based methods require various sensors, such as vibration, acoustic, pressure, infrared, Doppler, and a near-electric field, to detect falls. To identify fall occurrences, Werner et al. (2011) studied the vibration generated by a fall event from an Activity of Daily Living (ADL) event. However, this approach's high false alarm rate is a significant drawback.

On the other hand, vision-based methods can be categorized into two types: Red, Green, and Blue (RGB) images and depth images. Kinect is a commonly used equipment for extracting depth information in images; where used it to obtain a human bounding box, and used it to extract a human skeleton. Machine learning techniques such as Support Vector Machines (SVMs) were applied to identify fall events based on these features. However, Kinect has limitations when it comes to sunlight and outdoor environments. Convolutional Neural Network (CNN) has emerged as a game changer for RGB images. Lu and Chu (2018) used an object detection model (YOLO V3) that considers the relationship with the surrounding object to design their fall detection system. However, the performance of this approach heavily relies on camera angles, leading to the development of the pose estimation approach. The pose estimation method, OpenPose, can identify human skeletons and postures, leading to better identification of human motions used OpenPose to identify unstable centers of gravity during a fall event to detect fall events more accurately.

Structure of the Learning System

In general, older adults are at high risk of this injury due to changes in their body frame, physical and mental health, and cognitive alterations. In addition, fall risk depends on the individual, their physical environment, and their lifestyle. However, children and other individuals can also be prime victims. Falls are severe, but computer vision technology can detect them. In addition, fear of falling is an issue that individuals are prone to feel after their fall incident (Araya and Iriarte 2021). Many studies show different assessment methods and evidence-based approaches to deliver accurate data regarding fall risk causes and prevention methods.

Cross-References

► Locomotion and Human Tracking in Healthcare Robots

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Fall Risks

► Fall Risk Detection in Computer Vision

Fantasy XVI Online, a Massively Multiplayer Online Role-Playing Game

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F

Synonyms

MMORPG; Multiplayer game; Action adventure game

Definition

MMORPG = Massive Multiplayer Online Role-Playing Game is a multiplayer game designed to be played online

Multiplayer Game = a game that is designed for multiplayer mode where two or more players are expected throughout the entire gameplay

Action Adventure Game = a game that combines core elements from both action game and adventure game genres

Introduction

Final Fantasy 14 Online is an MMORPG developed by Square-Enix and published for the PC and PlayStation markets. It is popular to the point that they had to lock down the free-trial and stopped selling digital copies for a few months in order to keep the player countdown as to not overload the servers with the expected launch of "Endwalker," the latest expansion to come down the pipeline.

Gameplay

Players create a Warrior of Light to play through the game. With a focus on role-playing, each player takes the helm of one of the major Scions

or outside characters like Gaius. Featuring a variety of classes and various activities, there are many ways to approach the game including smithing, adventuring, buying houses, and raiding.

With 19 "combat" classes split between four tanks, four healers, and 11 "DPS," there is a wide variety of playstyles to choose from. From close-range physical DPS to long-range magical, healing, or tanking, you can truly be the "Warrior of Light" that you have always dreamed about in a huge fantasy game. Along with this, there are also 11 classes dedicated to crafting and gathering, allowing you to make your own gears and collect your own materials. Not only can you run dungeons or take on fantastic bosses, you can spend hundreds of hours crafting your own gears and playing the in-game markets to make "Gil" and buy wondrous prizes.

Tanks: Paladin, Warrior, Dark Knight, and Gunbreaker (tvtropes.org 2022)

The primary style of play for tanks includes gathering "aggro" through the use of enmity-generating attacks and a "tank-stance" that increases the amount gained per strike, along with damage mitigation and a few debuffs that can be applied to enemies. Each of the tanks has a different playstyle: Paladin and Warrior are the safest whereas Dark Knight and Gunbreaker are the risky options. Gunbreaker is a favorite for some gamers due to the high DPS combos along with the extremely precise barrier abilities. Figure 1 is an image of a game character as a Gunbreaker.

DPS: Monk, Dragoon, Ninja, Samurai, Reaper, Bard, Machinist, Dancer, Black Mage, Summoner, Red Mage, and Blue Mage

Physical DPS, Ranged DPS, and Magical DPS classes play quite differently from one another, and they often have wildly different abilities. For example, Summoner and Red Mage both possess the ability to resurrect other players, which often comes in handy during raids and major fights. Ninja is famous for its high burst potential, but many players prefer more consistent DPS output from classes like Samurai or Reaper. The king of

Fantasy XVI Online, a Massively Multiplayer Online Role-Playing Game, Fig. 1 A game character as a Gunbreaker wielding the newest Relic weapon

all of these is Black Mage, having been the undisputed lead of all DPS since the game's inception at a cost of limited mobility. Another favorite DPS is Reaper due to its high damage output and maneuverability, allowing it to zip around the battlefield and top the aggro chart with ease (see Fig. 2).

Healers: White Mage, Scholar, Astrologian, and Sage

Healers in this game are divided into two categories by the community: "Regen" Healers such as White mage and Astrologian, and "Shield" Healers like Sage and Scholar. Interestingly, the Astrologian straddles a line between the two categories given its abilities. While Regen healers focus on getting everyone to max health quickly with strong heals, Shield healers' main mechanic is to place shields on teammates in order to prevent major damage from taking place. One of the favorite healers is Sage due to the strong shield and its flexible cooldowns (see Fig. 3).

Reception

Originally facing lukewarm reception, each expansion of the game has received more rave reviews, culminating in being named one of the best MMOs of the generation. Many thought the hype surrounding the game had died with the culmination of the ShadowBringers storyline, with no one believing the following expansion would be able to top it. But the Endwalker expansion was not only considered a worthy addition, but it is now also being upheld as the bar of excellence in the MMO world. The game has achieved more credibility among even casual gamers, bringing another wave of new participants to the world of Eorzea. It was certainly helped by a generous free-trial offer that began around the initial outbreak of COVID pandemic. The free trial allowed users to play the original "A Realm Reborn" storyline as well as the hugely popular "Heavensward" expansion with two additional races and three extra jobs (Bussel 2022).

Fantasy XVI Online, a Massively Multiplayer Online Role-Playing Game, Fig. 2 A Reaper holding one of the new Major Relic Weapons

Fantasy XVI Online, a Massively Multiplayer Online Role-Playing Game, Fig. 3 A favorite Sage healer, not wielding a Major Relic Weapon

Tournaments

The game features a robust raiding community dedicated to "savages" and "ultimate" content that exist solely to challenge themselves to "races," that is, to be the first player to complete the new content as soon as it drops (mogtalk.org 2022). In addition, there was an official tournament in July 2022 for the game focused on the Crystalline Conflict mode that was region locked to Europe (Png 2022). In fact, one of the major game developers known as "Yoshi-P" can be regularly found participating in the PVP modes and fighting in Crystalline Conflict in order to personally test the competitive modes for the game and further improve it.

Conclusion

Final Fantasy XVI Online (FFXVI or FF-14) has become one of the best-selling MMOs, even surpassing internal sales metrics. The game experienced a huge boom of players during COVID-19, to the point that they had to stop offering the free trial and temporarily restrict people from purchasing the game in order to reduce the heavy load on their servers (Teixeira 2021). It has a large community that is generally positive and welcoming to outsiders. The community even offered a warm welcome to gamers who fled World of Warcraft when the controversies surrounding Blizzard came out. With continuously growing numbers, it cannot be denied that Final Fantasy XVI Online has become one of the biggest Massively Multiplayer Online Games in the world.

Cross-References

▶ Disney Toontown Online, A Massively Multiplayer Online Role-Playing Game

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Fighting Game

► King of Fighters, a Brief History

File Format

► Color: Pixels, Bits, and Bytes

Fingerprint Image

► Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features

Fingerprint Ridge Thinning

► Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features

Fingerprint Verification

► Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features

Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features

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Synonyms

Fingerprint image; Fingerprint ridge thinning; Fingerprint verification; Minutiae extraction; Singular point; Statistical features

Definition

One of the most popular forms of biometrics used for personal identification is fingerprints. The extraction of multi-features illustrates the diversity of data represented from fingerprint samples, allowing mitigation of the intrapersonal variable. This study uses multiple feature extraction based on statistical tests of co-occurrence matrices to overcome the drawbacks of previous methods and minutiae extraction to achieve high accuracy toward an efficient fingerprint verification system.

Introduction

The most important type of human biometrics is fingerprints. Fingerprints have been used for personal recognition in forensic applications, such as criminal investigation tools, national identity card validation, and authentication processors. The uniqueness and immutability of fingerprint patterns as well as the low cost of associated biometric equipment make fingerprints more desirable than the other types of biometrics (Maltoni and Cappelli 2009). A characteristic attribute of false fingerprints in the large view of complexly refers to forgery, combined with the actuality that

fingerprint samples are distinctive to each individual. In reality, fingerprints present a distinguished basis of entropy that is used for security implementations (Dodis et al. 2006; Dass and Jain 2007; Khan 2009). There are two classes of features utilized for the recognition system: global attributes and local attributes (Ebrahim 2017a). The global attribute pattern represents a distinctive modality of a singular point as the center point that is utilized for fingerprint recognition. The local feature represented from fingerprint's ridges data is called minutiae. The fingerprint verification (FV) system includes three processes: the fingerprint obtaining apparatus, extracted features, and verify features (Igaki et al. 1992). The dataset of FVC2002 is utilized to obtain the finger imprint by an optical device, which has high capability (Maio and Maltoni 1997). The extracted minutiae and minutiae verification are further obtained in the next stage.

A fingerprint authentication scheme is a model matching scheme that distinguishes the individual based on their fingerprint attribute (Maltoni et al. 2003). A number of various fingerprint classification systems have been improved using myriad classification approaches and datasets. Each classification method has its own specific characteristics that researchers capitalize on to advance fingerprint classification research using a particular dataset (Jain et al. 1997; Jea and Govindaraju 2005). In order to design a more reliable automatic identification system, preprocessing of fingerprints has to take place to enhance and extract fingerprint features (Wu et al. 2006; Rajkumar and Hemachandran 2011). According to Maltoni et al. (2009), most current fingerprint classification approaches depend on global attributes, including ridge orientation areas and singularities. Bazen and Gerez (2002) found that accurate classification of fingerprints is highly dependent on the orientation fields' estimation and singular points detection algorithms. Later, Arivazhagan et al. (2007) suggested a fingerprint verification system utilizing Gabor wavelets. Yazdi and Gheysari (2008) utilized co-occurrence matrices to verify the fingerprint image.

Preprocessing Fingerprint Enhancement

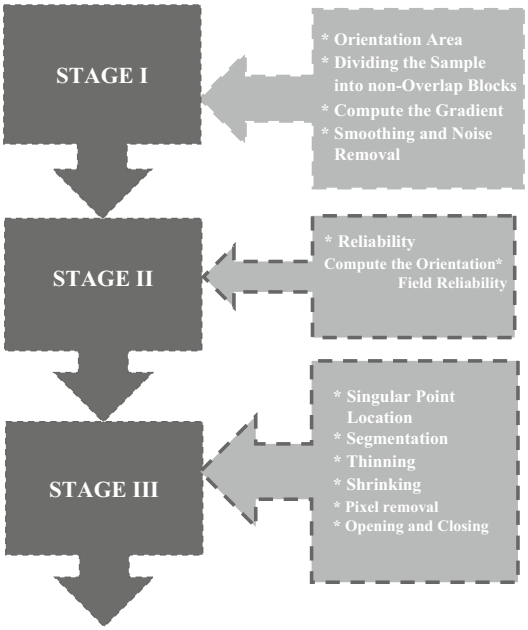
Image improvement of fingerprint samples is very important for FV to function correctly. The efficiency of the image of the imprint sample is influenced by noise in ridges produced by the under-inked region, varying the fingerprint attributes because of skin elasticity, where splits are from dry skin and wounds may cause ridge discontinuities. To preserve the high accuracy of the FV system, two procedures utilized in the unique mark recognition basis (STFT) analysis suggested by Chikkerur et al. (2007) are utilized here for image enhancement of fingerprints and procedures. The system can be shortened as follows: The image of the fingerprint is split into overlapping squares. Then STFT analysis is performed. The test productions are images of ridge orientation O(x,y) and ridge hesitation F(x,y). The next stage O(x,y) image represents smoothing of the orientation. For improvement, each overlapping square B(x,y) in the image has been rebuilt for the sample by creating improved blocks $B^0(x,y)$.

Feature Extraction Methods

The fingerprint sample illustrates a scheme of oriented texture and contains important data. This scheme utilizes an ensemble of dichotomizes to combine features through several measures and feature extraction methods, commanding lower cost and accurate FV. The approach utilizes multi-feature extraction at different measure techniques for classification of preexisting extracted feature systems, creating a large set of features (Ebrahim 2017b; Ebrahim and Sulong 2014). The performance of fingerprint images is realized by applying two methods based on singular point detection and fingerprint ridge thinning, as discussed in the next section.

Singular Point Detection Technique

The image of a fingerprint is made up of the design of ridges and valleys that is a copy of the individual imprints. The reference point is the point with extreme curvature on the convex ridge, and to define the single reference point reliably for all varieties of fingerprint samples, the orientation area, which characterizes the



Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features, Fig. 1 Singular point block method diagram (Kaas and Witkin 1987)

local orientations along the prevalent orientation, is utilized to distinguish the reference point. The reliability can also be calculated applying the method projected by (Ebrahim 2017a) and (Kaas and Witkin 1987). Figure 1 shows the block design for detecting the singular point and the implementation.

Orientation Area

The first stage of finding the singular point is computing the orientation area. The orientation field is critical for the computation of the reliability. The accuracy of the reliability robustly depends on the accuracy of the orientation area values calculated. Below are the steps for orientation calculation:

The fingerprint sample is split into a non-overlapping block of size (W × W). In this paper, W is set to 16.

The horizontal and vertical gradients $G_x(x, y)$ and $G_y(x, y)$ at each pixel (x,y) respectively are calculated applying simple gradient factors (Gonzalez and Woods 2008).

The ridge orientation of each pixel (x,y) within a W × W window at points [xi,yj] is calculated as follows (Ratha et al. 1995):

$$\theta(x.y) = \frac{1}{2}\tan^{-1}\frac{2G_{\mathrm{xy}}}{G_{\mathrm{yy}-G_{\mathrm{yy}}}}. \tag{1}$$

Because of noise, an inclined ridge, valley structures, and poor gray value, a low-pass filter can be applied to regulate the incorrect local ridge orientation. However, to achieve the low-pass filtering, the orientation image must be transformed into a continuous vector area, and the Gaussian low-pass filter can be used as follows:

$$\Phi_y(x.y) = \begin{array}{l}\sum_{u=-1}^{1}\sum_{v=-1}^{1} l(u.v) \\ \times\Phi_y(x-ul.y-vl)\end{array} \tag{2}$$

where l is a 2-directional low-pass filter with a complete unit.

The orientation area can be representing in this section.

Reliability

Meanwhile the singular point has the maximum curvature. It can be found by calculating the strength of the reliability peak applying the following equation:

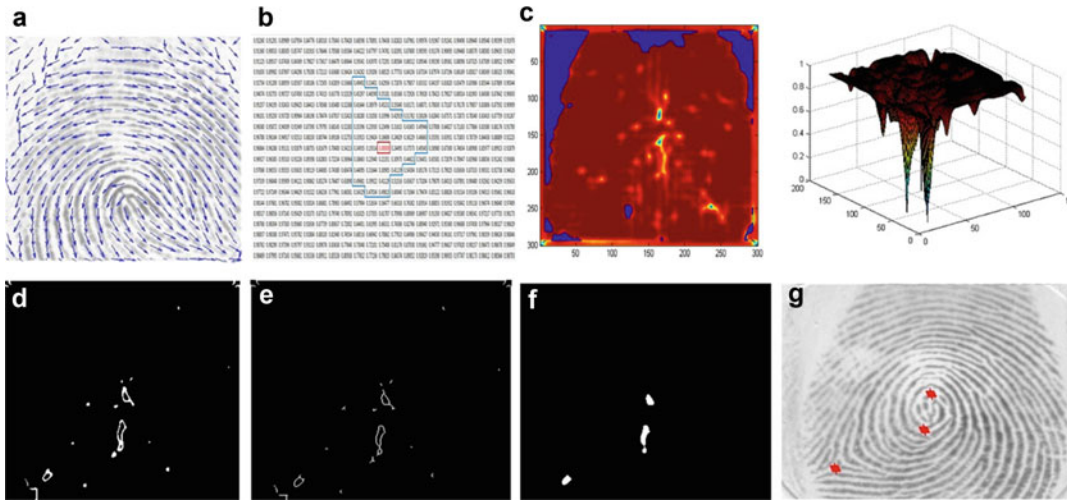
$$Y = 1 - \frac{Y_{\min}}{Y_{\min}}. \tag{3}$$

Figure 2 displays the orientation area reliability and the singular point value in the center. The reliability rate of the singular point is $= 0$, but the value of background is also zero. However, there is a contour around the singular point of the reliability value of the contour between < 0.5 and > 0, and this is the area of interest.

Singular Point Location

After calculating the orientation area reliability, the next stage is to detect the singular point place. This can be achieved by the following stages:

F



Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features, Fig. 2 The detecting of singular point by (**a**) Orientation field on original fingerprint, (**b**) Both singular point and orientation field reliability within the contour, (**c**) Reliability image map to three singular points, (**d**) Region of interest after the segmentation, (**e**) Singular point contour after thinning, (**f**) Filled singular point contour, (**g**) Singular point location on the original fingerprint

(i) The orientation field reliability needs to be segmented into two distinct regions. The region of interest contains the values > 0 and < 0.5.

The result of the segmentation can be seen in Fig. 2.

(ii) Thinning is the process of adjusting the width of contents of the image to one pixel while preserving the extent and connectivity of the original shape.

(iii) After thinning, all pixels will be removed so that the contour shrinks to a connected ring halfway between each hole and the outer boundary, and the rest will shrink to a pixel that will be removed. Figure 2 shows the singular point contour without any noise.

(iv) The singular point contour is well defined, and to determine the location of the singular point, the contour is filled using the morphological hole filling equation (Gonzalez and Woods 2008):

$$F\ (\mathrm{x.y}) = \begin{cases} 1-I(x.y) \\ 0 \end{cases}, \qquad (4)$$

where "(x, y)" represents the border of I; otherwise, H is equal to the input image I, with holes filled.

(v) Here, the singular point pixel can be found by performing the shrinking process for the singular point contour. Figure 2 shows the singular point pixel after applying the shrinking method, the position of the singular point on the original fingerprint, and Singular point pixel.

Fingerprint Thinning Minutiae Marking

Thinning is a procedure by which the sizes of the ridges are reduced. In each scan of the full imprint image of a fingerprint, every sample square represents (16 × 16) pixels (Maio and Maltoni 1997). This image along with other data will be recorded into the dataset (Jain et al. 1999). After obtaining this input file, it will undergo binarization. Usually, a vision of the distinctive mark will be obtained.

Normalization

Normalization is a procedure for fingerprint verification. Samples of fingerprints do not come in the same dimensions. Because of this, the samples need to be aligned suitably to confirm an overlap of the common area in the two samples of imprint by the orientation of the image to zero at the

reference point (Gonzalez and Woods 2008). Once all the features of each fragment have been extracted, then the feature values are normalized in the interval [0 1]. Normalization of features is very important because if the values of different features are in different ranges then the higher values dominate the lower values. Thus, the normalization technique makes the feature values in the same scales and ranges. The image of the fingerprint is split into a non-overlapping set of size W × W (for each 16 × 16) and the orientation that matches the most controlling orientation of the block (Ebrahim et al. 2018; Ebrahim and Ashoor 2018; Ebrahim 2018). After the process, the features of ridges in the fingerprint are represented in black and furrows are represented in white.

Multi-feature Extraction

There is a pressing need to develop a fingerprint verification system with software-based minutiae extraction and statistical features. The proposed approach is to extract the most suitable multi-features for classification. In this study, we combine a set of the strongest features. The effectiveness of the projected method has been evaluated through a comparison with several existing techniques for multi-features.

Tests have been executed depending on standard datasets. However, more accuracy lowers the popularization capabilities. In fact, the background minutiae extraction and statistical features have already managed to detect the differences in fingerprints, and statistical attributes are utilized by other FV systems, for example (Yazdi and Gheysari 2008). In this research, multi-features are extracted from different parts of the fingerprint, therefore increasing its selective power. There are also many outliers in each class, which are circled. The outlier is an observation that carries an irregular distance from its neighboring feature values that will result in misclassifications. Hence, it is observed that minutiae extraction or statistical features alone inherit some weaknesses, such as overlapping and outliers, which reduce their discriminating abilities.

Fingerprint Verification

Matching is an important part of fingerprint verification. It compares two features and returns a likeness score to indicate how comparable the two participating fingerprints are. The comparison depends on discovery of the Euclidean distance between the attribute of the conforming fingerprints.

The EER for experiment was computed by the FVC2002. In Table 1, the databases were split into four databases: DB1, DB2, DB3, and DB4. Each dataset contains 800 fingerprint samples collected from 100 persons, and each one is eight impressions. Sets of tests were carried out for each database, and the protocol is shown in Table 1. Yang et al. (Yang and Park 2008) used the tessellated invariant moment feature, Ross et al. (2003) used minutiae and ridge map features, Jin et al. (2004) used integrated wavelet and Fourier–Mellin invariant framework with four multiple training WFMT features, Amornraksa et al. (Amornraksa and Tachaphetpiboon 2006) used the DCT feature, Khalil et al. (2010) used statistical descriptors, and Flores et al. (2017) used Delaunay triangulations.

Conclusions

Low-accuracy fingerprint images require multi-features to expand distinction. The process for

Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features, Table 1 EER (%) evaluation of the current techniques

Technique	DB1	DB2	DB3	DB4	EER
Yang et al. (2008)	1.63	3.78	4.20	4.68	3.57
Ross et al. (2003)	1.87	3.98	4.64	6.21	4.17
Jin et al. (2004)	2.43	4.41	5.18	6.62	4.66
Amornraksa et al. (2006)	2.9	5.4	6.7	7.5	5.68
Khalil et al. (2010)	0.31	0.26	0.34	0.20	0.28
Flores et al. (2017)	0.125	0.125	0.75	0.75	0.44

FV comprises five sections: singular point detections, fingerprint ridge thinning, normalization, multi-feature extraction, and fingerprint verification. Moreover, minutiae extraction and the four statistical descriptors characterize the fingerprint texture. Each process plays an important role in fingerprint verification. Hence, to facilitate the accomplishment of such ambitious goals in the near future, researchers ought to perform statistical tests and minutiae extraction of fingerprint textures.

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Fire Emblem 14

► Fire Emblem Fates, Conquest

Fire Emblem Fates, Conquest

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Synonyms

Fire Emblem 14; Fire Emblem if

Definitions

Fire Emblem Fates released on June 25, 2015 in Japan and in 2016 in other regions for the Nintendo 3DS system. *Fire Emblem* is a tactical role-playing series that debuted on the Famicom with *Fire Emblem: Shadow Dragon and the Blade of Light* in 1990. *Fates* has three routes to play: *Birthright, Conquest,* and *Revelations*. This article will explain the background of *Fates* and what makes *Conquest* unique.

Introduction

Fire Emblem Fates is the fourteenth installment in the *Fire Emblem* franchise. *Fates* is split up into three different routes that have different game designs but share the same engine and mechanics. *Birthright* is designed to be similar to *Fire Emblem: Awakening,* the previous entry in the franchise. *Conquest* is designed for series veterans and those who seek a challenge. The *Revelations* route was added after launch with sandbox elements to allow players to have characters interact with other characters from the previous campaigns that may have not previously (Yamoto n.d.).

Unlike many strategy games of the time, *Fire Emblem: Shadow Dragon and the Blade of Light* differentiated units by giving them unique dialogue and personalities (Harris 2009). While the text was very barebones in *Shadow Dragon and the Blade of Light*, further entries in the series added a support system where units can talk to each other. After a certain point, units that support each other will assist each other in combat by increasing stats in combat.

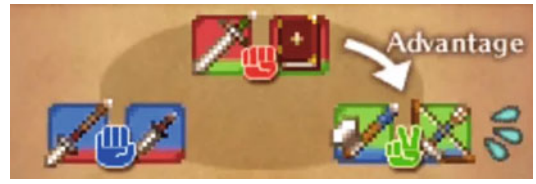
Fire Emblem Gameplay

Fire Emblem gameplay consists of moving units across a grid-based map to complete objectives, engage in combat, and manage character stats. Map objectives usually include seizing castles, defeating bosses, or defeating all enemies. Units in the player's army are differentiated by starting stats, the rate that stats grow (often called growth rates), how well they can wield a weapon, and class. A unit's class determines their movement type, growth rate modifiers, and weapons they can wield. The four movement types are infantry, armored, cavalry, and flying. Infantry units can be thought of as the basic movement level. Armor units have lower movement but have more defensive stats. Cavalry units can move more spaces but are slowed down by terrain, such as forests and hills. Flying units can move across any terrain with ease but are weak to arrows among other things. After a class has collected enough experience by performing actions, they can be promoted to a higher-ranking class, giving them more stats and weapons to wield. Common unit stats that are in many *Fire Emblem* games are Health Points (HP), Attack, Defense, Magic, Resistance, Speed, Skill, and Luck. Once a unit's HP reaches zero, they die. Attack is how much damage a unit can do in combat. Defense is used to reduce damage from an attack. Magic is used to calculate damage with tomes and other magical weapons. Resistance reduces damage from magical attacks. Speed affects a unit's dodge rate and

gives units the ability to perform a follow-up attack (often called doubling) if they reach a certain threshold of speed difference with an opponent. Skill is used to calculate how accurate attacks are and can be used to activate skills. Luck is used to manage the rate of critical hits, evasion, hit, and skill activation. A common mechanic that exists in many *Fire Emblem* games is the Weapon Triangle, where sword units have an advantage against axe units, axe units have an advantage against lance units, and lance units have an advantage against sword units. Other typical weapons are magic tomes, staves, and stones that allow their units to transform in battle. In most *Fire Emblem* games, weapons have durability that the player needs to keep in mind as to not be left defenseless. In most *Fire Emblem* games, when a unit falls in combat they are considered dead and will not participate in the story.

Fire Emblem Fates Gameplay

During the development of *Fire Emblem: Awakening*, it was internally planned to be the entry in the series if it did not sell well (Kantopia 2021). After *Awakening* sold very well, Intelligent System hoped to recreate what made it so popular while addressing mechanical criticisms. *Fire Emblem Fates* tells the story of Corrin, a noble born to Eastern-inspired nation of Hoshido but raised in the Western-inspired nation of Nohr. Nohr and Hoshido are on the brink of war when the game begins. Corrin must soon decide what nation to fight for. Fates made several changes to the weapon systems. Weapons no longer break and several have secondary effects, typically raising or lowering stats. Keeping with the themes of Western versus Eastern influences, each kingdom has slightly different weapons: swords/katanas, tomes/scrolls, axes/clubs, bows/yumi, lances/naginata, and daggers/shuriken. Hoshidan weapons are typically weaker when coming to raw strength while adding more stats in other areas, such as katana granting more speed while dropping defense and resistance. In addition, Nohrian staves have stranger healing capabilities than their Hoshidian counterparts, rods. However, rods can reach allies that are farther away. In addition, the weapon triangle has been updated to include all weapons, besides stones and monster classes (Fig. 1).



Fire Emblem Fates, Conquest, Fig. 1 The *Fates* weapon triangle

In *Awakening*, a mechanic called Pair Up allowed two units to occupy the same square with one leading and the other standing behind. The unit in the front will gain stats according to their partner's stats, class, and support level with the lead unit. They may also occasionally enter combat to perform extra hits or block enemy hits. This system was criticized by series veterans for being too overpowered and unstrategic as the bonuses were unreliable and unviewable. Enemies in *Awakening* are unable to use Pair Up. *Fates* responded to these criticisms by splitting Pair Up into Attack Stance and Guard Stance (Ramey 2020).

In Attack Stance, an adjacent ally will be able to join combat after the main unit has attacked with slightly less damage and the inability to perform a follow-up attack. In Fig. 2, Odin's damage, accuracy, and critical chance are in the left column while Ophelia's is in the middle column. The archer's statistics are in the right column.

In Guard Stance, two units can occupy two spaces. The lead unit will gain stats according to their partner's class, support ranking with the lead unit, and stats that each unit innately gives their support partners. In addition to stat gains, the pair gets a Guard Gauge. The Guard Gauge starts at zero shields and is full at ten shields. For every hit that the lead unit receives or deals, the shield raises by two. Once the Guard Gauge is full, the backing unit will jump in to fully block a hit from the lead unit. Units in Guard Stance cannot be hit by the foe's Attack Stance partner. If the units unpair or switch with other partners, the average Guard Gauge will average between the two

Fire Emblem Fates, Conquest, Fig. 2 Odin is attacking an enemy archer with assistance from Ophelia

Fire Emblem Fates, Conquest, Fig. 3 Keaton is paired up with Camilla in guard stance to attack an enemy Faceless

pairings. Enemy units can use both Attack and Guard Stance.

In Fig. 3, note the full Guard Gauge at the below the blue HP bar; Camilla will block the foe's next attack in combat.

Fates makes several changes to the class systems. Once again keeping with West versus East themes, many Nohrian and Hoshidan classes share characteristics. For example, the Nohrian class Outlaw can be seen as equivalent to the Hoshidan Ninja as they both are used to pick locks and are rather quick. There are also ways to reclass. Units can reclass into a stronger class starting at level 10. All units have a secondary class they can reclass to with a Heart Seal. Units can reclass into their married partner's class with a Marriage Seal. Units can reclass to the class that their best friend (units are best friends if they reach the highest level support rank, A+) has. Units will gain skills by leveling up in classes. Skills are buffs that can range from raw stats, more movement options, the ability to give stats to allies, more powerful attacks, etc. All main characters have personal skills that are innate and are exclusive to them.

If units gain a high enough support level, they can wed and have children. Children will be based on their father (Silas will always have Sophie as a child) while the mother will pass down their hair color. The opposite is true for Azura's child and Corrin's child, if Corrin is female. With the power of space-time travel, the children are able to be recruited into the player's army after beating their chapter. Child growth rates will change based on averages of their parents. Parents will also pass down their last equipped skill and their classes. Children can access these classes with a Heart Seal. If a child's chapter is done after chapter 18 of the main story, the unit will come with an Offspring Seal that allows them to gain access to a higher-level class with extra level and weapon rank that is curved to the enemies of the main chapter.

Units that have blood of the First Dragons can access Dragon Veins during battle. With them, players can change terrain, heal, or buff allies, damage or debuff allies, etc.. While Dragon Veins aren't usually necessary to a map's objective, they often provide more dynamic ways to strategize as each map has a unique effect.

At the start of the game, the player is able to customize their avatar, who's default name is Corrin. The player can customize their gender, voice, hair color, and accessorize them. The player can also choose their secondary class with their boons and banes. The boons determine what stats Corrin excels in by modifying growth rates. Likewise, the banes will determine what stats Corrin struggles with.

Between chapters, players will have access to My Castle. My Castle is a place where players can view supports, buy weapons and items, talk to other characters, forge weapons, and collect resources to customize the castle. My Castle serves as a downtime between chapters that allows players to plan out their next moves. Supports are built between characters as lines of conversation. Characters have up to three supports with their support partners, labeled C, B, and A. A fourth level of support is available to marriage candidates and best friends (S and A+, respectively). Forging weapons allow for weapons to become more powerful and for

players to name their weapons. Using the Mess Hall gives the chance to give slight buffs to allies for the next battle. The units Niles and Orochi have personal skills that allow them to capture certain enemy units. They can be recruited into the player's army at the Prison. Occasionally, players will be challenged to battles by mysterious forces and have to defend their castle. Players can also go online and visit castles that belong to other players and challenge them to battle.

The first five chapters of *Fates* are the same. In chapter six, the player can choose to send Corrin down the *Birthright*, *Conquest*, or *Revelations*. When selecting *Birthright*, the game gives the description of, "This path includes opportunities to freely accumulate experience points and gold. This will allow you to enjoy watching your characters grow faster." When selecting *Conquest*, the game gives the description of, "This path allows you to test your skills and devise complex strategies while progressing with limited access to experience points and gold." When selecting *Revelations*, the game gives the description of, "It is not recommended to select this path for your first playthrough. This route is best experienced after playing both the Defend Hoshido and Fight with Nohr paths."

Embrace the Dark

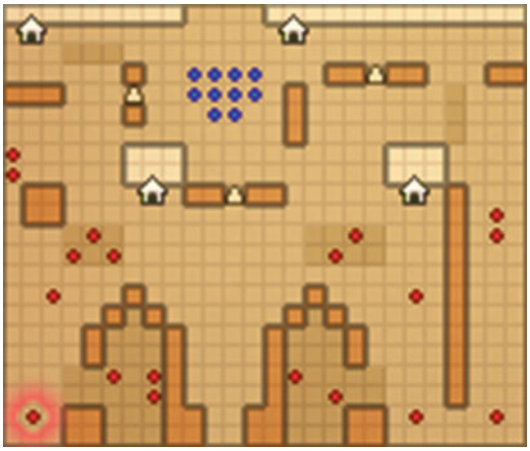
Conquest's "limited access to experience points and gold" changes the way players play the game. In the two other routes, players return to My Castle after every chapter. From there they can choose to scout on completed maps for extra enemies or choose side chapters provided they meet the conditions to unlock them. *Conquest's* limited maps force players to play tighter in the chapters they do have. *Conquest* players will have a harder time gaining supports between units, so experienced players will think about supports beforehand and dedicate some turns to building supports. On top of this, *Conquest's* maps are more difficult, having more varied objectives and side objectives. Enemy units have more skills, higher stats, and stronger artificial intelligence. Under most circumstances in *Conquest*, enemies will not engage in combat if they can do zero damage. In maps where the main objective is to have the player defend a point, enemies will sometimes refuse to fight the player and rush their objective. Enemies will also use Dragon Veins to their advantage. Another design difference from *Birthright* and *Revelations* is the lack of what the *Fire Emblem* community calls "ambush spawns." Ambush spawns are reinforcements that appear and take an action on the same turn. All of these factors work together to make *Conquest* more challenging and rewarding to players who can plan out complex strategies in advance.

Unhappy Reunion

The tenth chapter of *Conquest*, Unhappy Reunion, is thought by many *Fire Emblem* fans to be an example of a well-designed map. Many more believe that Unhappy Reunion is one of the hardest maps in the series. In chapter 10, Corrin is attempting to find a boat to transport their army to find the Rainbow Sage. To Corrin's surprise, the Hoshidian prince Takumi is sending an army to Nohr. Refusing to let Hoshidans on Nohrian soil, Corrin sets out to defend the port town.

In Fig. 4, blue tiles represent water tiles that only flying units can traverse, the darker tiles represent walls, and white tiles represent roofs. The northern section of the map is a boardwalk that has two houses. The middle of the boardwalk has a green section that Corrin must defend. If a unit visits them, the top left house will give ten thousand gold and the top right house gives a Master Seal. South of the gold house lies a breakable wall. To the left of the starting position is a Fire Orb, an item that mages can use. Next to the house that gives a Master Seal is a ballista. Another ballista can be found below the starting position. The house in the middle left gives a Dual Club, a weapon that reverses weapon triangle advantage and doubles its effects. The wall to the right of the house is breakable. The middle right house gives a defensive stat booster. At the southwest section of the map is Takumi holding an Elixir, an item that restores 99 HP. Takumi is standing over a Dragon Vein, but the game will not show its description. Behind the middle left section of units

Fire Emblem Fates, Conquest, Fig. 4 *Conquest* Chapter 10 Map



Fire Emblem Fates, Conquest, Fig. 5 Chapter 10 map with water drained

is Hinata, Takumi's retainer. Behind the middle right section of units is Oboro, Takumi's other retainer. At the southern part of the map are two boats with a Sky Knight flying between them. Ninja, Oni Savages, Archers, and Spear Masters will appear as reinforcements periodically on the left and right side of the map. More Sky Knights will appear from the South.

The opening position provides an advantageous position to defend the point: walls to the South and West, a Fire Orb, and Ballistae. On turn three, Camilla and her retainers appear, Beruka and Selena. Camilla is a Malig Knight, Beruka is a Wyvern Rider, and Selena is a Mercenary. Camilla and Beruka are flying units, so players will find the ability to cross water useful. On the fifth turn, reinforcements will start appearing and moving toward the green section (Fig. 5).

On turn seven, Takumi will activate his Dragon Vein, causing the water to drain from the map allowing all units to traverse them. All enemy units will then begin to rush their objective. Players who played defensively will find it hard or impossible to defend the objective without casualties due to the sheer number of units rushing at them.

Players who know about the reinforcements and Takumi using the Dragon Vein will tend to realize that playing defensively as the objective suggests isn't the best strategy. Trying to get out of the starting position to chip away at the enemy numbers before they rush toward the point will greatly help. Clearing out units near the middle houses early will give the players the ability to visit them, although it is not required. Due to the complexity of this map, Veteran players of *Conquest* will plan their playthrough around this chapter. Camilla and Beruka are very helpful as units due to their flying mounts. Being flying units, they are able to quickly traverse the map. Using heart seals, some players change their units' classes to have greater movement for this chapter. Elise and Corrin (if they picked Wyvern or Sky Knight as their secondary class) can reclass into flying classes. Jakob has the ability to reclass into a Paladin for cavalry movement. Buying weapons that have one and two range attacks will give the ability to counterattack the ninja. Breaking the wall next to the house containing the Dual Club will allow for the ability to exit the starting position and challenge Hinata faster. Camilla is one of three units by default that can wield clubs, so most players will give it to her if they chose to fight Hinata. Purchasing the Nosferatu tome for Odin will give him the ability to leech life from enemies. With this, Odin is able to challenge several units without requiring a staff unit to be nearby. Once Takumi drains the water, some players will try to congregate near the starting position to form a wall and challenge the remaining units. Camilla, Beruka, and any other high movement units are able to chase down the enemy flying units. If the fliers get too close, bow units will make quick work of them.

Unhappy Reunion's complexity, rewards, side objectives, and the ability to challenge the map in many different ways give players a sense of accomplishment when beating the chapter.

Eternal Stairway

The 21st chapter of *Conquest*, Eternal Stairway, is another map that is lauded by many that play as a map that tests players' knowledge by flipping traditional mechanics on their head. In Eternal Stairway, Corrin's army is invading Hoshido and is using an alternate route through the Wind Tribe lands to sneak around the main Hoshidian army. As they are traversing the Eternal Stairway, they are suddenly surrounded by monsters called Faceless and Stoneborns. The monsters are too vast in numbers to fight them all so Corrin and their allies are forced to find a way to escape.

Chapter 21's objective is "Escape with all units." All units must make their way from the starting area located at the bottom of the map through several large steps to the top of the map to escape. On the steps are Dragon Veins that will reduce all foe movement to zero. Scattered across the stairway are Faceless and Stoneborn. Faceless are one ranged enemies that come equipped with the Savage Blow skill, which reads, "When user triggers the battle, enemies within a 2 tile radius have their HP reduced by 20% after the battle." On harder difficulties they have skills that reduce accuracy for a specific weapon type. Stoneborn are enemies that launch stones at their foes from up to five tiles away. They come equipped with Wary Fighter, a skill that prevents enemies from making follow-up attacks. On harder difficulties, they come equipped with Renewal, a skill that lets them regain 30% of their HP at the start of the turn, and Heartseaker, a skill that reduces foes avoid. At the top of the staircase is a boss Faceless that holds an Arms Scroll, an item used to increase weapon rank. Additional enemies will endlessly appear at the top and bottom of the map. They come equipped with Wary Fighter, Grisly Wound (a skill that reduces enemy HP by 20% after battle), and Void Curse (a skill that prevents experience gain) (Fig. 6).

Fire Emblem Fates, Conquest, Fig. 6 Chapter 21's map

When tasked with a chapter that has a different objective, players will be forced to adapt their playstyle. One solution to clear the map quickly is to undeploy everyone except Corrin and a flying unit that can use Dragon Veins. They will then pair up and activate every Dragon Vein as they fly over the steps toward the end. While this is a valid strategy, players will miss experience gained by defeating enemies. Players have several options to maneuver up the stairway. In much the same way that chapter 10 forces players to defeat enemies early before they can swarm, Eternal Stairway forces players to defeat foes as they climb the stairway or fight the endless waves of monsters. Flying units have movement advantages as they can fly over the steps and easily access the Dragon Veins that are needed to freeze the monsters to keep the other units safe. Armored units are paired up with other units with more movement or have their class changed entirely as to not lag behind. Infantry and other mounted units can clear the Faceless on the sides of the stairs to make a path for units that can't take many hits from the Faceless and Stoneborn. In order to dispatch units with Wary Fighter, some players use blessed weapons, a class of weapons that deals extra damage to monsters. Other players use brave weapons. Brave weapons are a class of weapon that lets their wielders attack twice consecutively when initiating combat but makes them lose five speed. Brave weapons are usable at A rank so only units that have invested lots of time into a

specific weapon can use them. The Lightning tome is a brave tome that can be used a C rank instead of the usual A. Attacking the Stoneborn in Attack Stance will allow players to hit them four times in a round of combat if both attackers are using brave weapons.

Eternal Staircase is a map that flips traditional Fire Emblem game mechanics on their head in ways that force players to design new strategies using the units and resources they already have.

Conclusion and Discussion

Fire Emblem Fates: Conquest is a game that was designed for fans of strategy games, *Fire Emblem* veterans, and those who seek a challenge. *Conquest* rewards players who can analyze the problems thrown at them and plan out their moves in advance. The new mechanics of Attack Stance and Guard Stance allow for players to perform more complex strategies that previous entries did not allow for. *Conquest's* experience is crafted in a way that allows for player experimentation while also retaining its difficulty.

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Fire Emblem If

▶ Fire Emblem Fates, Conquest

First Nations

▶ Indigenous Language Revitalization with Stories and Games

F

First-Person Shooter

▶ Call of Duty Franchise, an Analysis
▶ Star Wars Battlefront (2004), an Analysis

First-Person Shooter (FPS) Game

▶ Overwatch: Team-Based Multiplayer First-Person Shooter Game

First-Person Shooter Games, a Brief History

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Synonyms

First-Person Shooter, FPS

Definition

First Person Shooter	A type of game play mode that lets the user (gamer) see the character they are playing.

FPS	First Person Shooter.
Maze War	A simple 2D maze type of FPS.
Wolfenstein 3D	A 3D version of Wolfenstein that came out 1981.
DOOM	The first true 3D game that came out in 1993, which launched what we now know of FPS.
Quake	A 3D game that took what DOOM made and made it better; it was also one of the first Esports games.
Duke Nukem	An FPS game that gives the main character more of the starlight with lines than he would use during game play.
Unreal	A 3D FPS game engine.
Unreal Tournament	A multiplayer game with area-based "deathmatches."
Deathmatch	A genre of multiplayer video game in which a player's goal is to kill or eliminate the opponent from the match.

First Person Shooter (FPS) Games

The first First Person Shooter (FPS) game came out in 1973. It was known as "Maze War." The game was created by Steve Colley, Greg Thompson, and Howard Palmer; it was playable over ARPANET between multiple universities (Jensen 2017).

The true FPS games arrived in the 1990s when 3D graphics took off and 3D game engines became available. Wolfenstein 3D (developed by id Software and published by Apogee Software and FormGen) came out in 1992. It was the first stepping stone for all FPS to date. The game was created by employees at iD software: John Carmack, John Romero, Tom Hall, and Adrian Carmack. These same people made the next FPS called "DOOM" that are still being used today to help create new FPS games (Coldewey 2013).

In 1996, another FPS game took 3D graphics farther by letting the player choose the 3rd person mode, as well as giving the character a voice. The game was called "Quake" that uses iD tech engine – the first game engine. Quake, published by GT Interactive, would become one of the first e-sports game that offered the winner a prize.

Some FPS games such as "Call of Duty" use real world events. "Call of Duty," published by Activision, would take the gamer to the beaches of Normandy, and all the way to future warfare that has yet to be seen. Activision came out with the game in 2003 for PC, adding different campaigns for different countries and the way they fought in each war. The game used iD tech engine.

The game "Duke Nukem" gave the playable character an icon for wisecrack speeches during gameplay. Scott Miller of 3D Realms created the game and sold the rights to Gearbox Software in 2010. Gearbox later released "Duke Nukem Forever" with higher quality graphics.

Unreal Engine

FPS would go even farther with better game engines (Buckley 2022). The second game engine was called "Unreal" which came from the company Epic Games. FPS games created using the first version of the Unreal engine include "Star Trek: Next Generation: Klingon Honor Guard" and an adaptation of Robert Jordan's "Wheel of Time" series. But the most memorable game was "Unreal Tournament" by Epic Games in 1999. "Unreal Tournament" was a multiplayer game with area-based "deathmatches." A deathmatch is a genre of multiplayer video game in which a player's goal is to kill or eliminate the opponent from the match.

The game that took everything known for FPS and rewrote it was "Halo: Combat Evolved" in 1999. Bungie made "Halo" into the largest game-based FPS ever. The game used artificial intelligence that would learn from the gamer and would make the gameplay harder at each level. It had different multiplayer modes, both online and offline. The game publisher Microsoft Game Studios later gave "Halo" to 343 Industries, which continued to make the franchise game.

FPS started out as a basic 2D type of maze game, and it evolved to a 3D Real Time-based strategy game – games where hearing and

speaking can either help you or hurt you in the gameplay – which added a new dimension of realism.

Virtual Reality

Virtual reality (VR) gave FPS yet another dimension of realism. Oculus Rift – developed by Oculus VR, a division of Facebook – came out on March 28, 2016, and with it came a new way of gaming (Robertson 2016). VR uses both regular and movement controllers. The player can still play the game normally but with a 360 degree or using their entire body in the gameplay. When you need to reload a gun in FPS VR, instead of just pressing a button, you have to move your hands to make it seem like you are actually reloading in real life. Even the military uses VR and FPS games to train new soldiers for combat.

First Person Shooter games have come a long way since the 1970s. With more advanced graphics, game engines, artificial intelligence, and virtual reality, FPS will continue to evolve and improve for years to come.

Cross-References

- ▶ Call of Duty Franchise, an Analysis
- ▶ Destiny and Destiny 2, an Analysis of an FPS
- ▶ Overwatch: Team-based Multiplayer First-Person Shooter Game

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First-Person Shooter, FPS

▶ First-Person Shooter Games, a Brief History

First-Person-Shooter

▶ Counter-Strike Global Offensive, an Analysis

Five Nights at Freddy's, a Point and Click Horror Game

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Synonyms

Horror game; Point and click game; Transmedia storytelling

Definitions

Point and click game:	An adventure game in which the player interacts mainly with the mouse or a pointing device.
Horror game:	A video game based on the horror genre.
Transmedia storytelling:	A technique of telling a single story or story experience across multiple platforms and formats.

Introduction

Technology has advanced dramatically over the past century, going from giant supercomputers and the invention of the radio to the portable computer better known as a laptop and a small device most people carry daily to do nearly anything we need. The same can be said about video

games, having gone from a colossal arcade machine to a downloadable application on a phone, computer, or console. Some of these games have gone as far as being a part of esports, though some would not and do not fall under that category. Indie horror games are made by either a small team or an individual using horror elements – whether they are terror or gore, or both. One such indie game has made an impact on the future of indie horror games, though it is debatable if it is for the better or for the worst. That game is Five Nights at Freddy's.

Five Nights at Freddy's, also known as FNaF, is an indie horror game released in mid-to-late 2014 by, at the time, a financially struggling game developer known as Scott Cawthon. According to Patricia Hernandez, a writer on Kotaku, "It's been called the 'scariest game in years.' It's at the top of iOS and Android app stores, it has torn up the Steam charts on PC. It has racked up millions and millions of views (and screams) on YouTube. It has hundreds of earnest fan games, and dozens of rabid fan theories" (Hernandez 2015). With each new installment or addition to the FNaF series, the fanbase grew bigger, adding on fan-made songs, remixes, gameplay, original content based on the series, and more. As of 2022, the Five Nights at Freddy's franchise has roughly nine games to its name, three book series based on the games, a movie that has been in the works for quite a few years now, and even an initiative to fund some game developers to work on their projects. Despite what negative or derogatory things some people have to say about Cawthon, his games, or the fanbase, there is no denying that the first game – the game that started it all – is what brought a new form of horror to light.

Gameplay

According to Nadia Oxford, a staff writer for USGamer, "Five Nights at Freddy's (FNAF) is a series of point-and-click horror games for PC and mobile made by independent game developer Scott Cawthon. The game's setting varies from game to game, but the premise between them remains the same: The player, looking through the eyes of the games' protagonists, must stay alive for five or six days against an onslaught of animatronics who want your blood" (Oxford 2021). The player's only defenses are the security cameras in the building, the office door, and the lights. The player has a limited amount of electricity each night. There are no playable characters, battle systems, or skill trees. It is a horror game with heart-pounding jump scares, but without the blood, gore, and extreme violence typically associated with horror films. The player's task is to survive, as the game title states, five nights at Freddy's. The challenges are Easter egg hunting and surviving each night without getting killed by the animatronic characters. Here are the basic steps to play the survival horror game as a security guard working the night shift:

1. Monitor the animatronics using security cameras and lights.
2. Manage limited resources wisely (e.g., Should the player close the doors to be safe or leave them open to conserve battery?)
3. Protect yourself from the animatronics by using a set of tools.

Each version of Five Nights at Freddy's offers a different set of tools. For example, in Five Nights at Freddy's, the player can control the two security doors connecting their office to the adjacent hallways as a barrier against animatronics in the vicinity. However, in Five Nights at Freddy's 2, there are no protective doors. Instead, the player must use an empty animatronic head and flashlight to defend itself against the animatronics. Five Nights at Freddy's 3 offers a monitor panel, which contains audio, camera, and ventilation. The common elements across the different versions are security cameras, lights, doors, vents, jump scares, mini games, phone calls, Easter eggs, and location closings.

Reception

At first, FNaF did not receive a lot of attention, but Cawthon's luck would turn around soon enough. A YouTuber/theorist who goes by FuhNaff created a video about the history of the FNaF franchise, its humble beginnings, its rapid rise in popularity, and its ever-increasing amount of content. In the video, he mentions that the game's first demo was released on a site called IndieDB but hardly anyone played the demo, except for an unknown YouTuber at the time, who was given the full game by Cawthon himself. Fast forward to August of that year, Cawthon released the full game on another site called Desura where another YouTuber, more well-known back then, did a "Let's Play" on the game, and it started to get noticed. People began to adore the game. With a growing audience and the more popular YouTubers playing the game, FNaF keeps expanding the fanbase (FuhNaff 2022).

Conclusion

Five Nights at Freddy's became a huge success after its slow start, racking up millions of downloads on various websites and mobile phones. FNaF has become an icon in certain parts of the gaming community, being recognized as an old game that some might consider it a game that should have lost traction long ago, while others see it a continuous story to be solved by the community as long as they find the right clues to solve the mysteries of the old haunted pizzeria.

The game has spawned a novel trilogy, the Fazbear Frights series, and the Tales from the Pizzaplex series cowritten by Scott Cawthon as well as graphic novels adapted and illustrated by other authors. A film adaptation was announced in August 2022 that the script had been written by Cawthon, Emma Tammi, and Seth Cuddeback, and the film will be produced by Blumhouse. Five Nights at Freddy's is a prime example of transmedia storytelling across multiple platforms and formats.

Cross-References

- ▶ Narrative in Video Games
- ▶ Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation

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Fluid Simulation

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Synonyms

Computed fluid flow

Definition

Simulation of fluid flow based on real-time computation on a workstation using different assumptions to approximate the overall behavior of the fluid.

Introduction

Digital simulation has been a well-explored research topic over the last decade. In particular,

the simulation of natural phenomena like fluid movement has attracted a lot of attention. There are mostly two different kinds of fluid simulation. One is for realistic movement of fluids in a high-performance computing area, and the other one is a real-time fluid simulation with desktop workstations. This literature review should give an overview on existing work in the field of real-time fluid simulation and the differences between different fluid representations. In the last decades, we can observe three different classes for real-time fluid simulations. The first one is dealing with fluid in a height-field environment that is very simple – but – yet efficient approach. This approach has drawbacks to show more sophisticated effects like splashing and bubbles. To calculate the fluid flow in all dimensions makes the simulation less efficient but enables to show effects like particles. Last but not least, the particle-based approach is the more recent one where each particle is a sample of the fluid flow, and with this samples the overall fluid flow gets approximated.

Related Work

In this entry, we overview various classes of fluid representations currently used for commercial applications in computer graphics. Three techniques are most commonly employed: *height field*, *cubic Eulerian grid*, and *particles*. Each family of fluid representation exhibits different characteristics that can fit different application demands. For a more specific introduction about existing techniques for fluid simulation, we refer the reader to one of the most comprehensive books about fluid simulation published by Robert Bridson (2008).

Particle-Based Fluid Simulation

The class of particle-based techniques uses a set of independent particles that approximate the fluid flow function by discrete values. The critical SPH drawback is the amount of computation time needed to process a large set of particles. The seminal work for SPH is described by Premoze et al. (2003) introducing a particle-based representation for fluid simulation and comparison to the traditional grid approaches. Later, numerous SPH techniques were presented following the same principle. For instance, interested readers are referred to the survey of Ihmsen et al. (2014). Then, we propose to detail various key features of existing SPH techniques: *surface tension*, *surface meshing*, *bubbles and foam*, *level of details and multi-scales*, *solver convergence*, *multiple liquids*, and *elasticity material*.

Surface Tension. The surface tension comes by design while using a height field for fluid simulation. In contrary, surface tension should be explicitly defined while relying on particles as claimed by Yu et al. (2012) and Schechter and Bridson (2012). Both papers present two different types of particle-based simulation that just not track particles for fluid simulation but also employ particles for modeling airflow around the fluid surface. Defining two kinds of particles and making them interact with each other enable to simulate surface tension. Furthermore, Yu et al. (2012) present a surface tracker to map particles into meshes, and Akinci et al. (2013) propose a method to simulate large-scale surface tension. However, Busaryev et al. (2012) extend the idea to use different particles to represent droplets and bubbles. Finally, using different particle types for different specificities is a very promising way to simulate natural phenomena in particles.

Surface Meshing. A major difficulty with particle-based fluid simulation is to transform free particles into a mesh for visualization and then render them without flickering artifacts. This problem is even more challenging to solve in the presence of splashing fluid. Yuksel et al. (2007) realized wave simulation and convert particles into a height field for fast rendering. To calculate collisions with the fluid particles, Akinci et al. (2012) propose a two-way coupling method for SPH fluids, using particles inside the solids. Also, a collection of previous works (Hoetzlein and Höllerer 2009; Batty et al. 2010) generate meshes from particles. Still, the problem of generating triangular surface meshes from particles remains a challenging problem with active research. For instance, Wojtan et al. (2010) introduce a mesh-based surface tracking method for

particle-fluid simulations. Finally, Ando et al. (2013) introduce a tetrahedral discretization for the pressure projection and a method to extract a smooth surface from particles.

Bubbles and Foam. Thanks to the computational power available on standard workstations nowadays, particle-based simulation offers more sophisticated natural phenomena and realistic effects like bubbles and foam. A collection of previous works (Hong et al. 2008; Cleary et al. 2007; Kim et al. 2007) simulate bubbles with SPH fluid simulation. The key idea is to mix bubble-labeled particles into the overall particle-based fluid. Moreover, Busaryev et al. (2012) extend the classical particle-based liquid simulation by incorporating bubbles inside the foam. To simulate a bubble effect with higher realism, the connectivity information of a Voronoi diagram should be built over the foam particles.

Level of Detail and Multi-scales. Levels of details are employed to speed up rendering while increasing the realism as much as possible with respect to available computer power. For instance, Solenthaler and Gross (2011) improve standard SPH by varying particle size at different regions of the scene to be simulated. The key idea is to use smaller particles where more details are needed, for instance, at collision location with obstacles and larger particles far away from the camera. In this direction, Yu et al. (2009) present view-dependent levels of detail technique to deal with large-scale scenes representing rivers with particle simulation in real time. Recently, Zhu et al. (2013) rely on an extendable dynamic grid to improve the efficiency. Finally, Edwards and Bridson (2014) introduce an adaptive fluid simulation enabling simulation at high resolution without the need of a fine discretization for the entire field.

Solver Convergence. Some techniques focus on increasing time steps for particle-based fluid simulation. For example, Macklin and Müller (2013) improve SPH fluid simulation with surface tension toward a better convergence and a constant density, allowing larger time steps using fewer particles. Finally, Solenthaler and Pajarola (2009) increase the time step of SPH fluid simulation by incorporating the particle pressure.

Heterogeneous Liquids. A collection of works allows the simulation of multiple liquids at different densities and viscoelastic properties inside the same simulation (Losasso et al. 2006; Ren et al. 2014; Shin et al. 2010). For instance, Lenaerts et al. (2008) present a SPH fluid technique to flow through a porous deformable using nonlinear materials. Also, Batty et al. (2007) combine fluid and solid with irregular boundaries. Recently, Robinson-Mosher et al. (2008) prefer to merge the momentum together.

Eulerian Grid Fluid Simulation

Another well-known class of approaches for fluid simulation is the 3D Eulerian grid. An important property of the Eulerian grid is its ability to represent complex 3D effects like splashing. Unfortunately, the quality of the fluid effects is limited by the grid resolution. An important work introducing 3D Eulerian grids is Chentanez and Müller (2011) using cubic grid cells to demonstrate complex 3D fluid effects. Lentine et al. (2010) improve the Eulerian fluid grid by dynamically adapting geometry from a given coarse grid. However, Brochu et al. (2010) prefer to rely on a Voronoi mesh interpolation, starting from a Eulerian liquid simulation. Also, Thürey et al. (2010) extend the Eulerian techniques by incorporating surface tension to offer more controllability over the fluid. Moreover, Raveendran et al. (2012) employ a sparse mesh to control fluid simulation. More recently, few works improve Eulerian liquid simulation by tracking fluid details (Bojsen-Hansen and Wojtan 2013) finely and enhancing the visual quality of the fluid simulation without using a finer grid (Zhang and Ma 2013). Finally, we notice that Eulerian-based fluid simulation is not often employed in production as a single representation, because of its inherent limitations. Thus, Eulerian grids are combined with other techniques to form hybrid solutions (as detailed in section "Hybrid Fluid Simulation").

Hybrid Fluid Simulation

We observe the high demand of hybrid techniques combining different fluid representations to produce large-scale simulation with fast

computational time and fewer memory requirements. For instance, an efficient strategy is to start with a height field as input to allow rendering of large-scale scenes and then to switch to more sophisticated approaches in the case where more details are required. Outstandingly, it is feasible to combine height-field, Eulerian, and particle-based methods to obtain efficient, stable, and flexible fluid simulation for breaking waves, waterfalls, and splash particles. Hybrid techniques enable high details on large water simulation in real time by switching between the different fluid techniques. One of the first hybrid fluid simulation techniques was proposed by O'Brien et al. (1995) combining height-field fluid simulation with a particle-based approach to generate spray effects. Later, this approach was improved by Chentanez and Müller (2014) by adding stability constraints and a combination with 3D Eulerian grid (Chentanez and Müller 2014). Finally, we notice that hybrid strategies improve the quality and flexibility of fluid simulation.

Fluid-Oriented Height Fields

Height fields are often used to represent simple surfaces thanks to its simple structure and fewer memory overheads. This representation is commonly used for game terrains and can be easily adapted for LOD and tiling. Height fields are an important class of fluid simulation motivated by an efficient use of resources. We refer interested readers to the excellent introduction of Cline et al. (2013) to the concepts of fluid simulation on height field. Also, we highlight two seminal works. Kass et al. (1991) approximate the shallow water equation to simulate wave refraction with depth, net transport of water, and boundary conditions with changing topology. Moreover, Stam et al. (1999) animate fluid in real time by splitting and simplifying the Navier-Stokes equation. More recently, Nielsen et al. (2013) synthesize waves, while resolving mesh self-intersection.

Mikls et al. (2004) introduce a computationally efficient layered water model to approximate the upper and lower water surface, allowing 3D water effects, like water flowing into a jar. More recently, Nielsen and Bridson (2011) introduce constraints on which a fluid simulation keeps close to a guided fluid simulation and to produce a predictable fluid simulation. For instance, Foster and Metaxas (1996) use height field for rendering effects like wave reflection, refraction, and diffraction. Also, Klein et al. (2003) describe how noise-based animation improves the appearance. Moreover, Müller-Fischer et al. (2008) reduce the computation time for a fluid simulation to be used in real-time applications like games. The key idea is to employ 2D height field with low resolution coupled with realistic shading effects, while freezing the simulation at non-visible regions. Finally, Yuksel and Keyser (2009) improve the visual appearance of height-field fluid simulations with real-time caustics using a generated caustic map.

Conclusions

All fluid techniques have their advantages and disadvantages. There is still a lot of ongoing research in the field of fluid simulation. At all techniques, we have observed that the time step between two iterations is critical. A too long computation delay damages the simulation in the form of stability or unpleasant visual results. Height-field fluid simulation is a simple and long-standing fluid simulation technique developed for computer graphics but is still very often used. The particle approach is newer with a lot of ongoing research which tries to fix known drawbacks to make the simulation even more realistic. Very interesting is the idea to combine the different fluid approaches to a hybrid approach. This helps to avoid the drawbacks of the different techniques but introduces more logical complexity to the fluid simulation. Overall, fluid simulation is still an attractive research area where no perfect solution exists.

Cross-References

- ▶ Lattice Boltzmann Method for Fluid Simulation
- ▶ Lattice Gas Cellular Automata for Fluid Simulation

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For Super Smash Bros.

▶ Super Smash Bros.: A Brief History

Formal Methods

▶ Timed Automata for Video Games and Interaction

Formalize

▶ Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design

Formative Game

▶ Hypermedia Narrative as a Tool for Serious Games

Fortnite: A Brief History

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Synonyms

Battle; Competitive video games; Esports; Royal; Shooter; Survival; Third-person

Definition

Fortnite = a video game that has two game modes: a co-op zombie survival mode and a Battle Royale mode.

Fortnite Friday = a weekly Fortnite tournament organized by Daniel "Keemstar" Keem and Faze Clan founder Ricky Banks.

Fortnite World Cup = an annual e-sports competition based on the video game Fortnite.

Introduction

This entry covers the history of Fortnite with the focus on the Battle Royale mode. It includes the story of live streamers who brought popularity to the game, the advantage Fortnite had over other

Battle Royale games, the start of Fortnite Friday, and the Fortnite World Cup. The entry concludes by discussing the effect Fortnite had on other games in the same genre and different genres.

Gaining Popularity

Fortnite was first released for early access in July 2017 with only one game mode: Save the World, which is the co-op zombie survival mode. When it launched, it did not gain much popularity with few people live streaming it. That all changed on September 26, 2017, when they launched their new Battle Royale game mode. It brought new players and streamers to the game because this game mode catered to a new audience of players who enjoyed third-person competitive shooters. After the release of the Battle Royale, more players and streamers started to take notice of Fortnite. One such streamer was Tyler "Ninja" Blevins with his flashy playstyle and skill that seemed to be greater than everyone else. He started to gain popularity not only for himself but also for Fortnite as well. Ninja went on to become the first streamer to get his own skin in the game that featured his iconic spiked blue hair and yellow headband (Rishabh 2020).

Fortnite's Cross-Platform Play and Free-to-Play

Fortnite had several advantages over other Battle Royale games that helped propel its popularity. When it was first released in 2017, Fortnite was the first Battle Royale game available on both the PC and the consoles. This gave Fortnite a huge advantage because it attracts not only PC players but also PlayStation 4 and Xbox One players. Fortnite was later released on mobile devices and Nintendo Switch as well, making it playable on almost any platform. Sony who owns PlayStation refused cross platform play at first, but in 2018 Sony decided to allow their players to join the PC and Xbox One players in playing Fortnite (DigiZani 2021). Since day 1, Fortnite is free to play, making the game accessible to every gamer in the world.

Fortnite Fridays

Fortnite Friday is a weekly Fortnite tournament organized by Daniel "Keemstar" Keem and Faze Clan founder Ricky Banks. (Faze Clan is a professional esports and entertainment organization founded in 2010 and headquartered in Los Angeles, California.) In this tournament, two teams of two – comprised of either a Twitch or YouTube streamer or a big-name celebrity – would compete in a best of three series where they played in the same game and competed to be the duo with the most kills for that game. There were ten tournaments over 10 weeks, each with a prize pool of $20,000 (Twin Galaxies 2021). This brought attention to the community's desire for a competitive scene in Fortnite's Battle Royale mode. The tournaments even attracted the attention of the famous rapper Drake who gave a shout-out on Instagram to Brett Squires who was competing. Forbes and ESPN both took notice as well writing stories related to the weekly tournaments (Erzberger 2019).

Fortnite World Cup

In July 2019, Fortnite held it biggest event to date beginning on July 26 and lasting through July 28 with four tournaments and a whopping $30 million prize pool. The tournament venue was Arthur Ashe Stadium where the US Open for tennis is hosted. But for those 3 days, the stadium was home to thousands of Fortnite fans cheering on their favorite Fortnite competitors. Competitors had to go through a 10-week qualification before they were able to compete in the tournaments.

Outside the stadium was a miniature Fortnite amusement park featuring a zipline, mini-golf course, a giant pirate ship, and a giant ball to roll around in. In between the tournaments, there was a Marshmello concert and teases of the tenth season of the game.

Even with all those things going on, the main attraction of the event was still the competition. The four tournaments played during the event were a creative mode showcase, celebrity Pro-Am, duos championship, and a solo championship featuring 100 of the world's best Fortnite players. The duo and solo championships were what most people came to watch as they were going to show the highest level of play that had ever been seen. A European duo of Emil "Nythrox" Bergquist Pederson and David "aqua" Wang won the 3-million-dollar duo competition; 16-year-old Kyle "Bugha" Giersdorf won the 1-million dollar solo competition (Webster 2019).

Fortnite's Influence

With Fortnite becoming one of the most popular games in the world, it is natural for other games to try to copy its success formula. One popular feature in Fortnite is the battle pass system, which is essentially a system that rewards players for playing the game and offering more rewards for players who decide to upgrade to the paid version of the battle pass. The free to play model with microtransactions to customize the game has also become a popular feature with the success of Fortnite.

Conclusion

Fortnite had a slow start in July 2017 with the Save the World mode, but it quickly gained popularity with the launch of the Battle Royale mode in September 2017. With the introduction of Fortnite Friday, the competitive scene was beginning to develop, which led to Fortnite World Cup in July 2019 – the biggest event in Fortnite history. Fortnite will go down as one of the most influential games in history.

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Foundations of Interaction in the Virtual Reality Medium

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Synonyms

Artificial intelligence; Conceptual blending; Immersive design; Immersive systems; Interactive design; Spatial cognition; Virtual reality

Definitions

The *medium* of virtual reality (VR) can be defined as the unique set of practices and novel affordances that emerge when using VR and is distinct from work built for screen-based or other media.

Introduction: VR, a Technology, and a Medium

VR systems bring together a family of technologies to create a convincing computer-graphical space around the user. These spaces can range from the photorealistic to the abstract and can include a host of objects, interactions, and effects. While many VR systems are primarily visual (the focus here), others can involve other sensory modalities such as haptic or olfactory feedback. Better understanding VR as a technology and as a medium will aid in distinguishing between media technologies, genres for using such technologies, and particular works. *Technologies* here refers to hardware and software that are researched, developed, and used. A *genre* is a style of using some input/output capabilities, and a *work* is an instance of a genre" (Goguen and Harrell 2014). The *medium of VR* can then be defined as the unique set of practices and novel affordances that emerge when using VR. Genres of VR will continue to emerge as conventions are innovated and established. Works created that uses the *medium* of VR will be distinct from work built for screen-based or other media. This understanding of VR is especially important for understanding its role as a medium for works of computer-based art (Bates 1992) such as videogaming and interactive narratives (Jenkins 2004; Thiel 2009).

The *technology of VR* can be defined as any combination of devices and software that produces a sense of virtual *exteroception* and *proprioception* in a user. Exteroception refers to perception of an external environment. Proprioception refers to perception of one's own body (Fotopoulou 2015).

These technologies most typically include: (1) real-time computer graphics, (2) dynamic visual interaction including: a panoramic image space with positional and orientation tracking, (3) sensory elements including stereoscopic vision, a head-mounted viewing device, and spatial audio, and often (4) motor elements including peripheral devices such as handheld controllers. These elements combine to produce a sense of *virtual exteroception*, providing a sense of a tangible virtual environment, and of *virtual proprioception*, providing the sense of a tangible virtual self. VR can include less interactive work, such as 360-° film, or highly interactive work, which could include peripherals such as gloves equipped with sensors and treadmills to simulate physical movement.

This section introduces definitions of these various technologies, discusses their key aspects, and demonstrates examples of how each – individually and in combination – provide unique impacts on creating VR systems.

F

Real-Time Computer Graphics

Real-time computer graphics are familiar to most users from media forms such as computer games and animated feature films. However, while animated films often use pre-rendered computer graphic images (CGI), VR environments and models are rendered as-needed in response to user input such as gaze, position, movement, and gesture while users explore and interact with the virtual environment. VR experiences can be built from 3D models and environments implemented synthetically using CGI software. Alternately, VR imagery can be captured from the physical world through techniques such as photogrammetry and videogrammetry to build 3D models from photos and video. Finally, VR environments can be created using techniques integrating both synthetic modeling and physical world capture-based modeling. For example, in *Hospital with One Entrance,* artist Deniz Tortum uses a laser scanning device to capture the physical dimensions of a hospital's operating room and then imports these data into VR software to program interactivity (Tortum 2016).

Key Graphics Technology Considerations

Computer graphics used in VR require a frame rate of up to 75 frames-per-second (fps) in order to ensure smooth movements and avoid noticeable *judder* to the user. Systems that fail to provide high quality resolution and frame rate cause end users to perceive *judder* and may result in motion sickness. Given these requirements, VR computer graphics systems must be equipped with powerful enough graphics processing unit (GPU)

capabilities and have low system *latency*, or time between user input and updates in displayed graphics.

Key Graphics Design Considerations

Real-time graphics provide both constraints and affordances for designers. Latency and judder are examples of *constraints*.

System designers must negotiate these constraints, for instance, *tethering* consumer VR headsets to powerful GPU-packed computers using cables. These challenges have inspired research and development efforts focused on designing more efficient hardware to enable higher-quality VR experiences on affordable mobile devices with less processing power. Given that VR systems enable the design of nuanced interfaces and experiences tailored to individuals based on their gaze, position, movement, and gesture over time, overcoming power and latency issues enables more impactful uses of the medium in educational, training, medical, and therapeutic contexts (Chu and Cuervo 2016; Lai et al. 2017).

Orientation and Positional Tracking

Users can navigate their visual environments more freely in VR than in other screen-based media. This is due in part to the combination of a panoramic virtual environment with orientational and positional tracking. Positional tracking and orientation tracking refer to the ability of VR systems to track user movement in the physical world, and translate that movement to the virtual environment. The degrees to which VR systems support translating user movement from the physical world to the virtual environment is referred to as the "degrees of freedom" (DOF) of the system. *Orientational tracking* means that the system tracks the rotational movement of a viewer's head, thus allowing a user to look freely in any direction in the virtual environment. All current VR systems enable orientational tracking. *Positional tracking* follows the user's translational motion and positions the user in a 3-dimensional environment. Higher-end VR systems enable positional tracking. These types of user tracking, combined with the complete panoramic image space and a wide field-of-view, create a visual environment for the user that is closely connected to natural perceptual activities. Moreover, in VR, the CGI spatial environment also implies shape, volume, location, and physics, encouraging users to look under, around, or through elements in space (Smith 2017).

Key Tracking Technology Considerations

Positional tracking in VR is generally achieved through sensors which may be internal or external to the head-mounted display or controller. Some hardware also uses embedded sensors to track this kind of motion. *Orientation tracking* is typically tracked using a combination of accelerometers, gyroscopes, and magnetometers embedded into the hardware. For positional tracking, laser- or camera-based sensors can be used. Each of these technologies has tradeoffs for design: for example, camera-based systems can be more accurate, but require processing power and connections sufficient to avoid latency and have additional privacy considerations.

Key Tracking Design Considerations

Positional and orientation tracking activate the visual space outside the user's immediate field of view, allowing users to glance and reach at things in the periphery of their vision and to lean or reach towards and away from elements in the scene. *Intentional looking* and *direct address* are two techniques for accounting for this in design. For example, consider a VR experience in which the spatial imagery around the user initially goes pitch black and then lights flicker on a little bit later. The user might react by looking curiously around using and investigating the full panorama image space to see what changed. The user's investigation of the space is motivated and intentional, more active than receptive. *Direct address* describes the "two-way process of a user both seeing and being seen" by other characters within the environment and by the virtual environment itself (Sutherland 2015). The tracking devices allow the system to change in response to a user's attention: for example, objects appearing only when the user is gazing elsewhere.

Placement of objects within the environment given the constraints of the positional tracking system and the *tethered* display is of key concern when designing for HCI in VR. For example, while activities such as "crouching" or "crawling" in VR games can provide an exciting sense of immersion, they can easily result in user fatigue if repeated too often during the experience.

User tracking and spatial design also has emergent effects in multiuser environments. For instance, nSpace is a project exploring collaborative aspects of VR for design tasks. This system uses a special sensor for hand tracking to visually represent the user's hands. This enables interaction with user interface components that exploit the 360 ° visual representation. This enables users to move through virtual environments and provide more specific and relevant feedback on objects and instructions to other users using *subjective* – in relation to a user's body (Johnson 1987; 2007) – rather than *objective* language, such as the absolute position of an element on a screen (Zaman et al. 2015).

Stereoscopic Vision, Head-Mounted Displays, and Spatial Audio

The combination of stereoscopy and head-mounted displays (HMDs) connects VR systems closely with natural visual perception. Stereoscopic vision in VR produces the illusion of depth and three-dimensional space and is achieved by displaying parallax angles of images through dual lenses. These dual images originate from different perspectives and slightly overlap, such that users fixating binocularly on a point will perceive elements images on the same relative coordinates as a single object (Tam et al. 2011).

HMDs must also be equipped to deliver spatial audio that is synchronized with the visual experience. Finally, many companies and researchers are working towards enabling eye-tracking in consumer VR systems.

Key Stereoscopy, HMD, and Spatial Audio Technology Considerations

As discussed above, most consumer VR headsets are *tethered* to powerful GPU-packed computers with high power consumption and thermal output. However, active work is being done to develop more efficient HMDs that can deliver higher-quality VR experiences on more efficient and wireless devices. HMDs can also deliver spatial audio which simulates natural human localization techniques using sound clues. The widespread use of consumer speech recognition systems, work in 3D binaural sound reproduction, and spherical microphones are advancing the quality of spatial audio capture and playback (Jarrett 2017).

While eye-tracking adds an additional computational load to systems, it can enable *foveated rendering* techniques, which are processes for reducing the workload on the system by high-quality rendering of the graphics the user is looking at and lower-quality rendering of the visuals in the user's peripheral vision (Guenter et al. 2012; Padmanaban et al. 2017).

Key Stereoscopy, HMD, and Spatial Audio Design Considerations

Stereoscopic depth enables VR to convincingly situate users in CGI spatial environments, resulting in a sense of a physical relationship to objects and characters (Schröter 2014).

Tethered HMDs limit users' range of translational motion, but research and releases to the consumer VR market are trending towards improving phone-based, wireless, all-in-one HMDs. As barriers to entry for VR HMDs become lower, HMD design must anticipate and address the "brick in the face problem" which results from the opaque quality of the headset.

Given that the eyes provide a crucial means of nonverbal communication in social contexts including gaming, eye tracking technology can be used as input to achieve better customization. Other VR experiences such as *The Enemy*, a journalistic VR artwork by photographer Karim Ben Khelifa addressing global conflict (Kennedy 2016; Lacey 2016), allow for dynamic changes to the experience's narrative (e.g., events and dialogue) and staging (e.g., lighting and mise en scène of the virtual environment) based on the users' embodied input to the system using artificial intelligence. For example, features including users' translational motion, head motion, directional orientation, and proximity to each other

and to virtual characters are used as proxies to track users' attention, nervousness, and biases (e.g., asymmetries of attention and nervousness). This real-time user tracking triggers feedback by the system including changes to behaviors of the nonplayer characters, appearance of the users' avatar, voice-overs, and the virtual cloud cover (thereby impacting the lighting). Eye-tracking capabilities can also enhance the evocative potential of this genre of VR experiences. In social VR, eye-tracking technology has been used in conjunction with computer vision algorithms which align and blend a 3D face model with a camera's video stream of the user (Frueh et al. 2017). These strides demonstrate how artificial intelligence will help to enhance connection and interaction in multiple-user VR scenarios and third-party gameplay viewers.

Furthermore, spatial audio can be a powerful tool to present sounds from any direction, control user attention, give users cues on where to look, and provide an immersive VR experience (Grau 2003). Spatial audio in VR has the potential to be applied as a powerful design tool for evaluating planned architectural designs in combination with soundscapes prior to physical construction (Echevarria Sanchez et al. 2017). Tools such as *Mediate VR* which enable the evaluation of space and soundscape designs through remote, asynchronous, voice-driven collaboration. Forward-looking designs of HMDs must be able to stream and play spatial audio in real-time, with tools such as *TheWaveVR* introducing the concept of social platforms which host immersive VR music concerts.

Peripheral Devices

VR peripheral devices enable additional forms of user input, output, and interaction in the immersive environment. Although not the focus of this article, it is important to consider key types of such devices.

Key Peripheral Device Technologies

Peripheral device input can include the positional tracking of hands and a variety of controller-like inputs. Peripheral device technologies includes *haptic technologies*, which describes a form of human-computer interaction involving touch. These peripherals range from controllers or simple touch screen devices with button-based controller paradigms, to a joystick, remote, or mouse, as well as devices which enable gestural interaction ranging from the 1990s "data glove" (Premaratne 2014), treadmills, to *Leap Motion, Microsoft Kinect,* or the *Myo* armband. Peripherals can also include biometric devices such as wireless wristbands that monitor real-time physiological signals for affective computing interfaces, EEG-based biometrics for brain-computer interfaces and more. Sensory-output-based peripherals may also include vibrating floors and mats, electrical muscle stimulation for muscle-computer interfaces, and olfactory output devices.

Key Peripheral Device Design Considerations

In combination with the technologies presented in the previous sections, peripheral devices present additional design opportunities and challenges. For example, while handheld peripherals and gloves can enable users to manipulate virtual objects, developers must account for the effect of users seeing their own hands. Systems that enable standing in combinations with tracked handheld peripherals afford the user the ability to be able to reach into virtual environments and do things, requiring nuanced handling of embodied input.

By leveraging biometric devices that provide real-time physiological data or manipulate the sensations of the user's body, an additional layer of immersion is added to the experience. For example, recent research has used muscle stimulation through gentle electrical impulses as a new approach to rendering the haptics which afford the repulsion of a wall or gravity pulling down the weight of a heavy box (Lopes et al. 2017).

Creating VR Experiences

Introduction

This section presents two theoretical approaches that can underpin and motivate the design of VR experiences. The first, constraints and affordances, is crucial to organize approaches to the many new interaction paradigms and sheer

variety of design choices. The second, conceptual metaphors and blends, suggests a way to bring metaphorical thinking into the virtual environment in a way that can be used both for creative purposes and for efficient design.

Constraints and Affordances in VR

The technologies that enable the possibilities of immersive VR environments also present both *sensory constraints* and *physical/motor constraints*. *Sensory constraints* are limitations in being able to provide visual information to the user. This may result in a lack of framing around the content of the experience, or a lack of self-representation of the user's body in space. Many VR systems focus on visual and auditory constraints. *Physical/motor constraints*, which are limitations in the physical capabilities of the hardware design, setup, of ability for users to move in the physical world. This may result in a lack of freedom in users' movements and interactions with their physical surroundings, which may result in safety risks.

The psychologist James Gibson provided a useful term when discussing what technologies enable or constrain: he defines an *affordance* as what the environment offers or furnishes to the user (Gibson 1977, 1979). In these terms, VR is a unique medium with the potential for novel interaction mechanisms given the particular constraints and affordances of the technology. In VR, the designer has a close hand in creating and varying the *perceived affordances* presented to individuals within the experience (Norman 1999).

The design choices of developers, in conjunction with the aforementioned technological elements of the medium, also shape the *sensory affordances* of VR systems. Especially of note are their *visual*, *tangible*, and *gestural affordances*. *Visual affordances* are visual cues which invite users for action in the form of visual guides or floating user interface (UI) elements. For example, in any given VR experience, users can have either *no body*, *an object instead of a body*, a *partial body*, their *own body*, *another person's body, or even multiple bodies*. *Tangible affordances* are provided by peripherals which enable *haptic* interaction and cues in the environment, such as different vibration patterns being transmitted to the users' fingertips through controllers or point and click devices. *Gestural affordances* provide cues which invite users for gestural interaction, such as cues to virtually touch or pick up objects.

Conceptual Metaphors and Blends in VR

VR experiences and tools can be thought of as a *performance* between users and their virtual environment (Laurel 2014). One potentially effective way to design such mediation is to build *interface metaphors*, a set of visuals which build on existing notions, actions, and *phantasms* (Harrell 2013) to facilitate meaningful and intuitive interactions in VR. Interface metaphors are in turn grounded in conceptual metaphors, which are mappings between ideas (including mental images) that are grounded in sensory-motor action (Lakoff and Johnson 1980). For example, forefingers and closed hands are typically associated with pointing and grabbing; hence, selecting virtual objects may be achieved by virtually pointing and gathering virtual objects may be accomplished by virtually grabbing.

They key to designing strong interface metaphors is keeping them intuitive to the user (Galloway 2012). Users should be able to infer coherent actions based on these metaphors unless they are explicitly designed for creative effects (for instance, an interaction mechanism that is difficult to perform can be useful to represent a difficult action in a VR game). This can be very challenging in such an immersive environment, given that the user can do and perceive many things. Anticipating the user's inferences is important, and by taking an environmental approach to design one can begin to think this way. Likewise, for creative projects, anticipating users' expectations can allow for the creation of surprising and meaningful narratives.

Conclusion

Virtual reality is an important set of technologies and media. This is because, as the name indicates, its technologies seek to make use of many of the modes of interaction that humans have in the "reality" of the physical world while enabling the new "synthetic" possibilities of the virtual. It has also been said that objects in the physical

"real" world can lose their reality due to layers of mediation (Baudrillard 1995) and experiences in virtual environments can have real physical world impacts ranging from bullying to discrimination (Harrell and Lim 2017). In light of these complexities, VR's technologies and their constraints and affordances must be account for while creatively making, subverting, and adapting them for impactful and powerful experiences.

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► Design Framework for Learning to Support Industry 4.0

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Game Bot

▶ Detecting and Preventing Online Game Bots in MMORPGs

Game Bot Detection on Massive Multiplayer Online Role-Playing Games (MMORPGs) Systems

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Definition

Massive multiplayer online role-playing games (MMORPGs) clients (the players) connect to online servers (the virtual worlds). The servers constantly update the client software with the sights, sounds, and happenings in proximity to the player. Attack against MMORPGs is performed by automatic program, bot, that plays automatically and performs cheating actions

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against players' moves. In such a context for bot detection, we identify all types of detection algorithms that are able to recognize the game players that are not human users by using several statistical features (e.g., machine learning, statistics on log analysis, etc.). For example one algorithm can perform a comprehensive statistical analysis of user behaviors defined in game activity logs and then set up several threshold levels that can be used to distinguish between game bots and human users.

Overview

A game bot is a program that plays games automatically instead of human users, typically used for game cheating. Game cheating identifies "Any behavior that a player uses to gain an advantage over his peer players or achieve a target in an on-line game is cheating if, according to the game rules or at the discretion of the game operator, the advantage or the target is one that he is not supposed to have achieved." Cheating can be performed at several levels. For example, it can be done by exploiting a bug in the software or protocol or by exploiting vulnerabilities of various people involved in operating or playing online games. When we talk about game bot, we consider the cheating performed by an automatic program that can play without break; consequently it can accumulate money, items, and score much faster than normal human players.

In the recent years, the use of game bots has become one of the most serious security threats to MMORPGs. In fact a game results in significant damages in terms of the economic game cost. For example, Castronova (2007) studied the monetary damage caused by game bots in World of Warcraft, an MMORPG developed by Blizzard, by considering several aspects including customer service cost, a technical cost for bot enforcement, etc. The indirect cost of game bots was approximately 18 million USD per year. To address these issues, game vendor invests significant efforts to design solutions for mitigating game bot activities (Bethea et al. 2010). The most fundamental point for solving the problem is to have a strong mechanism to identify game bots. Several detection techniques have been proposed by game vendors. In the following, we describe the most practical ones used in the real online games.

One of the proposed techniques is to focus on the detection based on repetitive activities of game bots, which are typically found in game log activity. Such technique shows that game bots frequently repeat certain activities that are different from human user ones. Consequently, using this analysis, researchers proposed a new bot detection framework that uses a metric called "self-similarity measure." Self-similarity is used to show the similarity of user actions as a function of the time lag. This method is designed for finding repetitive patterns, especially periodic patterns of the series of actions and their frequency. The method considers several actions such as moving pattern to provide a strong self-similarity that is able to resist to the changes of target games in their following updates. Another strategy is to construct a model of proper client behavior against which actual client behaviors are compared (e.g., system call model). More precisely remote system calls are compared to a control flow model generated from the binary code during its training execution.

A different approach to protecting against client misbehavior in client-server settings is to ensure that clients manage no privilege state that could affect the server; this is commonplace for games today. This approach is for the client to simply forward all unseen user inputs to the server, where a trusted copy of the client-side computation monitors these inputs directly; this is implemented in the Ripley system. This system replicates a copy of the client-side application on the trusted server, and any event is sent to the replica of the client for execution. The system monitors results of the computation, both as computed on the client side and on the server side using the replica of the client-side code. Any discrepancy is flagged as a potential violation of software integrity.

Another common approach to defeat a variety of cheats against the game bots which involves augmenting the client-side computer with monitoring functionality to perform cheat detection is PunkBuster. Such approach requires consideration of how to defend this functionality from tampering, and some commercial examples have met with resistance from the user community (e.g., World of Warcraft's Warden). More in details, PunkBuster is searching in the local memory of the client a certain pattern that can be a symptom of game cheating. PunkBuster based its own efficacy on pre-built database that contains several cheating behaviors in the form of patterns to search for in memory.

History

Several works on game bot detection using several detection approaches have been published. Ahmad et al. (2009) presented a first study, in 2009, by evaluating the performance of various classification algorithms for bot detection in the game called "EverQuest II." They introduced the terms "gatherers," "bankers," "dealers," and "marketers" for categorizing bots with several characteristics such as demographic data, characters' sequential activities, statistical properties, virtual item transactions, and network centrality measures. At the same historical time, in 2008, Thawonmas et al. (2008) also presented an early study that tried to detect game bots using bots' behaviors such as repeating multiple times the same activities than normal users. Their detection rules were based on simple threshold values. Bethea et al. (2010) presented a defense technique based on symbolic execution, used for analyzing the client output and determining whether that output could have been produced by a valid game client. Their proposed technique cannot detect cheats that are permitted by game clients that do not change their behaviors as seen at the server level. At the same time on the network side, Kang et al. (2012) proposed a bot detection mechanism based on the differences in communication patterns between bots and human users. Kang et al. (2013) also proposed a game bot detection method based on the players' network features. Such methods can detect bots with high accuracy. In addition to individual bot detection, researchers also design mechanism to detect bot groups. Chung et al. (2013) proposed a method that cluster features by behavioral similarities using the K-means clustering algorithm and then detecting bots in each group by using support vector machine (SVM), and Mitterhofer et al. (2009), Chen et al. (2009), and Kesteren et al. (2009) proposed similar methods with general features such as the moving paths of characters, respectively. Those works use the characteristic of game bots to move with fixed routes set up by bot programs. Such methods can be applied to most MMORPGs. More recently new detection techniques have been proposed. For example, in the paper (Lee et al. 2011), the authors extend their works into a more generalized model; while their approaches (Mitterhofer et al. 2009; Chen et al. 2009; Kesteren et al. 2009) simply used the single feature of moving path, they build a generic framework with several features by designing a self-similarity algorithm to effectively measure bots' activity patterns, which was previously used as a means of analyzing network traffic (Crovella and Bestavros 1997) or developing intrusion detection systems (Kwon et al. 2011). Such method is significantly robust to changes in the configuration settings of bot programs compared with existing approaches (e.g., (Mitterhofer et al. 2009; Chen et al. 2009; Kesteren et al. 2009)) because the method focuses on all activities and it represents the state of the art of game bot detection techniques used nowadays.

Conclusion

Game bot detection has changed considerably by the first introduction of the online game technology. Several techniques for cheating have been addressed, and new attack techniques have been invented. The business around the online game

has grown a lot, and the attackers are really focusing on such context since it is right now a new business model that attracts cyber criminals that are active in Internet context.

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Game Control

▶ Gaming Control Using BCI

Game Design

▶ Domain-Specific Choices Affecting Design Effort in Gamification
▶ Protection Korona: A Game Design on Covid-19
▶ Underground Design of Kaizo Games

Game Design and Emotions: Analysis Models

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Synonyms

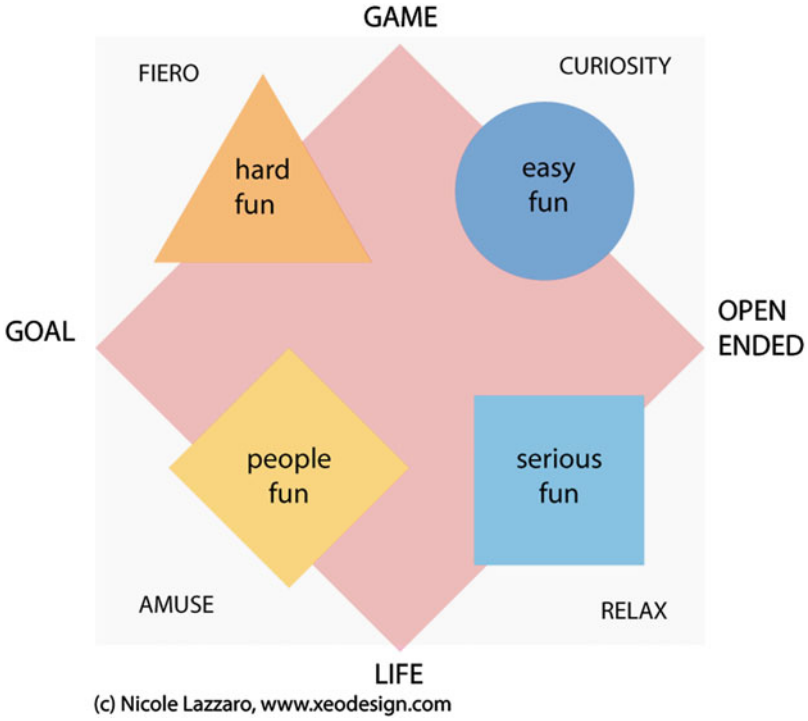
Engagement; Immersion

Definitions

Grinding	The process of engaging in repetitive tasks.
Farming	Performing repetitive actions to gain experience, points, or some other form of in-game currency.

Introduction

Evoking a complex emotional response in players is a characteristic trait of successful interactive entertainment, and different models have been proposed to help designers in creating and analyzing compelling emotional experiences. This entry introduces three well-known approaches: the "Four Fun Keys," the "MDA Framework"



Game Design and Emotions: Analysis Models, Fig. 1 Player experience under the lenses of the Four Fun Keys (Lazzaro 2004)

(including the "8 Types of Fun" model), and the "AGE Framework" (including the "6–11 Framework").

The Four Fun Keys

Introduced by psychologist and player experience expert Nicole Lazzaro in the whitepaper "Why We Play Games" (Lazzaro 2004) and later in (Lazzaro 2009), this model identifies four main types of fun with different characteristics which are able to deeply engage players by relying on different sets of emotions. In particular:

- **Hard Fun**: relates to frustration and pride. It involves the act of mastering increasingly difficult challenges.
- **Easy Fun:** relates to curiosity, surprise, and awe. It engages players thanks to visually and content rich environments able to stimulate their imagination.
- **Serious Fun:** relates to excitement and relaxation. It engages players by providing meaning and offering a purpose for the overall experience.
- **People Fun:** relies on social interactions to make players bond in and outside of the game. Here friendship and relatedness become central to the playing experience.

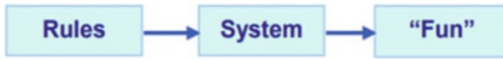
To be successful, games should then focus on one or more of these key types of fun in order to deliver an emotionally rich experience and engage players to the fullest.

The Four Fun Keys are summarized in Fig. 1.

The MDA Framework and the 8 Types of Fun

Proposed by game designers and scholars Robin Hunicke, Marc Leblanc, and Robert Zubek in (Hunicke et al. 2004), the MDA (Mechanics, Dynamics, Aesthetics) was the first serious attempt to discuss games in a more formal and rigorous approach. Central to the MDA is the idea of a game as an *artifact* whose consumption can be broken down into three separate components (Fig. 2):

These, in turn, have design counterparts as shown in Fig. 3 where each abstraction layer is defined as follows:



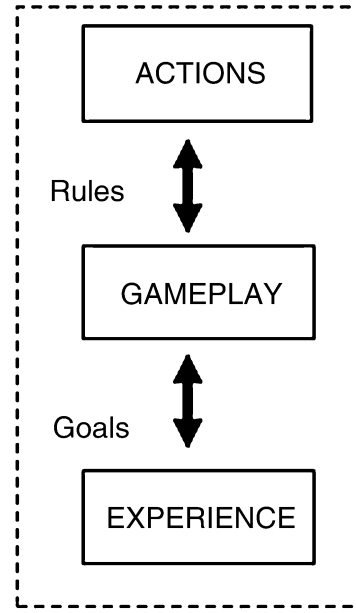
Game Design and Emotions: Analysis Models, Fig. 2 Consumption of games according to the MDA framework

Game Design and Emotions: Analysis Models, Fig. 3 Design counterparts for the elements identified in Fig. 2

- **Mechanics:** the particular components of the game, at the level of data representation and algorithms
- **Dynamics:** the run-time behavior of the mechanics acting on player inputs and each other's outputs over time
- **Aesthetics:** the desirable emotional responses evoked in players when they interact with the game systems

Aesthetics, in particular, is discussed further in a dedicated taxonomy called the "8 Kinds of Fun." These include:

- **Sensation:** game as sense pleasure. This can be created by visuals, soundscape, and proper pacing.
- **Fantasy:** game as make-believe. This is about empowering players and offering new experiences.
- **Narrative:** game as drama. Storytelling helps giving a sense of purpose to the whole experience.
- **Challenge:** game as obstacle course. New challenges, finely tuned with players' own skills, will easily keep them engaged.
- **Fellowship:** game as social framework. Playing with friends is often more engaging than playing alone.
- **Discovery:** game as uncharted territory. This is a fundamental trait of adventure games.
- **Expression:** game as self-discovery. Typical of sandbox games where players are free to experiment as they please.



Game Design and Emotions: Analysis Models, Fig. 4 Schematic representation of a generic game according to the AGE framework

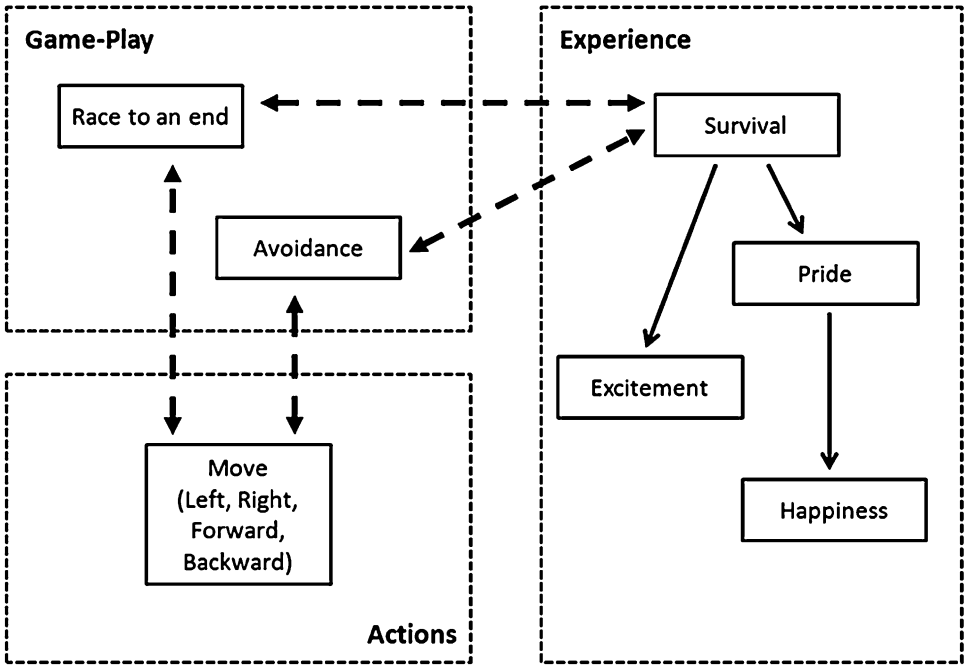
- **Submission:** game as pastime. It may involve grinding or farming and can be used to balance "Challenge" to change the overall game pacing.

For example, a game like "The Sims" (see https://en.wikipedia.org/wiki/The_Sims) can be discussed in terms of discovery, fantasy, expression, and narrative, while a game based on the "Final Fantasy" (see https://en.wikipedia.org/wiki/Final_Fantasy) franchise would be most likely centered on fantasy, narrative, expression, discovery, challenge, and submission.

The AGE and 6–11 Frameworks

The 6–11 Framework was first proposed by game design Professor Roberto Dillon in the book *On the Way to Fun* (Dillon 2010) and then formally integrated into a MDA-inspired model named AGE (Actions, Gameplay, Experience) in (Dillon 2014).

The model describes a game as three main systems (see Fig. 4) interconnected to each other via in-game rules and goals and defined as follows:



Game Design and Emotions: Analysis Models, Fig. 5 AGE Framework analysis for the 1981 Konami arcade game Frogger (see https://en.wikipedia.org/wiki/Frogger)

- **Actions**: the core, atomic actions a player can perform in a game, usually described in terms of verbs. Examples are moving, jumping, kicking a ball, punching, shooting, taking cover, etc.
- **Gameplay**: the resulting play that players achieve by using and combining the available actions according to a predefined set of rules. These can be either higher-level concepts or verbs, for example, fighting, race-to-an-end, territorial acquisition, etc.
- **Experience**: the emotional experience that engages players during the game while trying to reach certain goals, overcoming obstacles, or solving problems.

The experience is then exemplified, thanks to the 6–11 Framework, which comprises 6 basic emotions and 11 instinctive behaviors such as *Anger*, *happiness* (*or joy*), *fear*, *sadness*, *pride*, *excitement*, *survival*, *curiosity*, *self-identification*, *protection* (*or caring for*), *greed*, *aggressiveness*, *revenge*, *competition*, *collecting*, *communication*, and *color appreciation.*

The underlying idea of the model is that a subset from the emotional palette outlined above can be triggered by the game and then can interact with other elements as the game progresses, engaging and motivating players throughout their playing sessions. Once the experience is outlined, one or more of its components can then be linked to the gameplay for analysis and discussion purposes, allowing designers to formalize their ideas and overall vision (see Fig. 5, for an example).

Different game genres may emphasize a different set of emotions, and the model can be applied to serious games as well (Dillon 2013).

Cross-References

▶ Emotion-Based 3D CG Character Behaviors
▶ Game Thinking X Game Design Thinking

- ▶ Psychology in Game Design
- ▶ Semiotics of Computer Games
- ▶ Videogame Engagement: Psychological Frameworks

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Game Design Evaluating Using Machine Learning

- ▶ Automated Game Design Testing Using Machine Learning

Game Development

- ▶ Game Thinking X Game Design Thinking
- ▶ Strategies for Design and Development of Serious Games: Indian Perspective
- ▶ Underground Design of Kaizo Games
- ▶ Virtual Reality Game Engines

Game Development Leadership Tips

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Synonyms

Administration; Conduction; Direction; Management

Definition

Leadership is the craft of inspiring and guiding people to achieve an objective. In game development, this objective is completing a game within time using the allocated budget while presenting great quality.

Introduction

Video game development has deeply technical details inherently related to it. The most basic of them is the hardware on which the game will run. It will shape, in part, the software and often artistic assets.

There are also more subjective points related to it like: how fun is it, how beautiful are its graphics, how good is its music or sound, and how good is the composition of all the above items. The game story and the many subtleties of the craft can also be summed to these elements.

There is still one factor that is decisive for the success of failure of the vast majority of games: the people who make those games. While many games had great ideas and teams behind them, capable of producing all a great game needs, many of them still failed to deliver as a good product.

There are certainly many explanations for why they failed. When hearing such teams, they will often refer to the lack of a common vision, communication problems, micromanagement, and other problems which are clearly not related to

the game itself (DeMarco and Lister 1999). This category of problems is game production related.

Among the many things needed for a game production process to succeed, leadership is a major facilitator. In this text, a few leadership tips will be presented in order to give a head start to any leader working in the game industry or person seeking education on the topic. Those tips are pieces and bits of information and ideas I came up with during my 10 years of experience in leadership positions in game development.

Tip 1: Love

The love in question is much similar to the one parents, more often than not, have for their children: They want their children to grow and to achieve their dreams. They will provide whatever subsidies on their reach.

More reason for this the similarity with parental love being a working technique and value for leadership is the psychological mechanism of transference and countertransference. Leaders will be in a position where their approval to their subordinates will effectively affect (Stone et al. 2000), if not their chances of survival (Stone et al. 2000) or quality of life, at least their work life. This has a strong similarity to the relationship between parents and their children.

The people working under the leaders will often, therefore, try replicating the relationship they had with their parents with their leaders, due to the transference mechanism. This means their expectations, at least in a subconscious level, will be similar to those they had with their parents.

Sometimes their relationships are or were troubled, causing some degree of hostility toward the leader. Often those relationships were based on love and trust.

Leaders acknowledging this should be prepared to gracefully handle hostility and manage the expectations of their subordinates. The hostility handling may have positive impacts on the person often going beyond the work environment, similar to the effects of a therapy session. Once the leader gets through with it, which may not be always possible, strong bonds are often formed.

Loving the people they command is a value some successful leaders have. More than a practice, this value guides leaders into intuitively relating well to many people as well as shaping policies and actions that foster a healthy work environment.

Finally, it's not without a reason that love is the central value within religions. It had deep appeal for the human psyche, and it's a strong element that leaders should keep in mind.

Tip 2: People

A very common mistake committed by new team leaders, especially those from an engineering background, is not figuring out their work instruments changed. Someone working in the game industry will often be a person whose working tools are programming languages, digital content generation tools, source control systems, and IDEs. Once promoted to a leadership position, this can change overnight: The working instruments of a leader are the people.

This change has often deep implications: Where once a person's job was to implement some feature or create content, the leader is now responsible for getting some other person to do so. This requires a fundamental change in the kinds of skill used and sometimes mentality.

Instead of answering how something should be done, a more appropriate question for a leader to answer is: Who would be the best person or people to do it at this time? Answering this question requires the leader to understand the talents of each individual on his or her team. The leader should be able to answer: "What is a person good at?"

Still, answering properly who is the best person to do a given task takes more than just understanding the skills of each individual. Sometimes even highly skilled team members will not perform well on assigned tasks.

One of the common causes for it is motivation, or rather the lack of it. Determining what motivates a person is, therefore, also a key factor for being a good leader. While motivation factors can vary from person to person, there are some which

are commonly reported and, for this reason, can be addressed proactively by the leader.

One such motivation element exists when someone doesn't understand the goal of a given task; this person will often be unable to evaluate how good a solution is or, at times, even if the solution is correct. While some individuals will ask for the information required to clarify what they need, a good leader cannot assume this to be the case. Proactively ensuring people have enough context is a crucial part of the job.

Another factor is that one has to work with people he or she prefers not to. This might, at least, put strain on the shoulders of those doing it. Understanding the affinities of a team and dealing with them can be a vital part of distributing tasks and, thus, of being a leader in game development.

Also, even when the leader chooses the right person for a task at a given time, circumstances may change during its execution (DeMarco and Lister 1999). From unpredicted technical difficulties to personal dramas, there is a whole universe around this chosen person which can change. A good leader should always be attentive to his or her team members, being always ready to help them whenever possible.

As a reminder, dealing with people involves far more than logic, algorithms, task allocation, or aesthetic sense. It involves questions like self-esteem, sensitivity, sense of righteousness, pride, and many others to be listed. The tool to deal with all of them is communication.

Tip 3: Communication

When working with people, the most important tool to use is communication (DeMarco and Lister 1999; Acton 2014). It should be done far more often than what would feel natural to a leader: Many things which are obvious to the leader may be even counterintuitive to some team members.

Other times, people will simply not tell the leader when they disagree or have problems with something. Considering the issues tolerable, they will often prefer to avoid conflict in order not to look bad in front of the leader or even do it in attempt to become the boss (Stone et al. 2000). This is often a problem, as it may lead into growing tension over an accumulated set of small things.

Worse yet, what may feel like a small problem to some of the team members can, in fact, be perceived as something big for the leader. Also, possibly even more worrying is the opposite case: when something small for the leader feels big for the team member. As there is an undeniable power relationship, this can make the subordinate feel fear.

No good relationship, personal or professional, comes from fear. So, it is an important part of leadership to handle communication properly: both in the sense of content and form.

One possible point to start with, regarding communication, is the tone of voice used. Much of what humans communicate is nonverbal, and the tone of voice, for instance, is a very important factor. Care must be taken to pass the correct information.

Apart from the tone of voice, a leader must ask for feedback and give feedback whenever possible (Acton 2014). It's usual for a team member to be passive on giving or asking for feedback. The leader should be prepared to proactively work around it.

A good instrument for feedback is having periodic one-on-one meetings with each and every team member periodically Stone et al. 2000; DeMarco and Lister 1999). Their objective should be having a human exchange, to prevent possible latent tensions from rising.

Performance feedback should, ideally, be given in a task basis, or even in a subtask basis for long tasks, especially if this means for the leader to demonstrate multiple times a day approval for a well-done job. Showing disapproval is just as important: The earlier the leader shows it, the earlier the team member can correct the cause of it. A good leader should always keep in mind that when he or she does not communicate criticism, it is denying a chance to the person receiving it to improve.

Finally, if a leader gives enough context to the team members, passing information about the projects and about the company, they will be far more

likely to understand their contribution to the big objectives. This practice provides great help in motivating people: Humans, as shown by religions, feel the need to be part of greater plans and have higher purposes.

Tip 4: Responsibility

Another sudden change for those who become leaders is the scope of their responsibility. Before being in a leadership position, each individual is accountable for his or her work alone. This is obviously different for leaders. Still, there are not so obvious changes worth mentioning.

A typical situation which exposes these differences is the case when the newly appointed leader is confronted by his or her boss regarding some issue on the project. Any good leader will understand who was responsible for the part which had issues. The sometimes the counterintuitive part is deciding on how to proceed from this point.

Many beginner leaders will, sometimes in the human act of self-preservation, explain to their bosses that the issues are coming from a specific team member (Stone et al. 2000). This is an inappropriate approach.

The leader is responsible for the results, regardless of the circumstances. The leader should take responsibility for the current state of the project at all times. If a team member is underperforming, it is the responsibility of the leader to deal with it before it becomes a problem to the project.

Moreover, in the cases where the leader doesn't have the appropriate people or resources to handle a task, it is his or her responsibility to inform it to the boss as soon as this information becomes available.

Tip 5: Sincerity

One of the most important traits of a leader is sincerity. The people working with a leader are intelligent adults. More often than not, the team members will notice when the leader is not being sincere.

More than just noticing, people will first try to understand why the leader is being insincere. And often they will pay back behaving the same way: being insincere as well. This is not the trust environment expected from the successful teams.

Some new leaders sometimes will consider they have good reasons to be less than sincere with their teams. Sometimes they actually want to protect them from criticism from other people or teams; other times there are bad news such as possible layoffs ahead and the leaders don't want the team to lose focus. Still, a leader should understand that if he or she can cope with it, so do the team members.

As intelligent adults, they most likely faced bad news before (Stone et al. 2000). Most of them had a broken heart; most of them heard of people dear to them dying: This certainly dwarfs any bad news a job in the game industry can bring. Going further, when presented with difficulties those people may help in finding good solutions to it or, when not possible, either start coping with the issue or accepting the loss.

Still, a caring leader will have concerns about how a person will feel after criticism is delivered. A caring leader won't want to hurt people's feelings or self-esteem. He or she will deliver the criticism making it clear that the problem is not the person, but the action, behavior, or result achieved.

Tip 6: Trust

Trust is an absolute key element when working with people (Sinek 2009). It is one of the foundations of human society: When humanity was young, threat was all around. There were no cities where you could be safely away from predators. Carnivores such as wolves, bears, and big felines were a common threat. Sleeping was particularly dangerous for humans in the wild.

Survival required cooperation (Sinek 2009). There had to be people awake during the night to alert the others of possible attacks, and the lives of the entire group would depend on these people doing their jobs. The group had to trust them completely and reciprocate, or else this equilibrium would eventually fail.

This was the reality of the human race for a period far longer than recorded history up until when this text was written for the first time. This is not just a fad, a modern behavior; this is something so old that it is likely even recorded in human genes: Humans are programmed to cooperate with each other, but this cooperation requires trust.

Let's now take these ideas what most would consider a somewhat safer environment: the office of a game studio. The central idea remains: A good leader should understand that if he or she wants to be trusted, the first thing to be done is to trust the people with whom he or she works.

And what does trusting someone mean? It means primarily that the leader will delegate work as one of his or her main activities. Moreover, this should be done trusting that the people receiving the tasks will be able to accomplish them well. Also, just like a loving parent, a leader, especially if he or she is a good engineer, should understand that it's time for the team members to shine and his or her to support it.

A natural consequence of this line of reasoning is the inherent absurdity of micromanagement. It not only simply doesn't work with engineers but also increases turnover. Micromanagement screams out loud: "I don't trust you can do your work well and on time." Any leader seeking trust must absolutely forget micromanagement.

Returning to the concept of reciprocity, for a leader to have team members who will answer honestly, the leader should first answer honestly. If a leader wants the team members to take risks, the leader should be the first to take those risks and take them for the sake of the team.

For example, if the leader disagrees with some decision, he or she should state so while reminding that still his or her role is to uphold this decision. The team members will reciprocate up to the point they believe a leader will go for them, and they will just believe by seeing the leader to it first.

There are, also, situations when a team member loses the trust of the leader. If this happens, action should be taken by the leader. Often involving the team on deciding which action to take is a good option. A leader trying to dodge this kind of problem will pass a message that there are no consequences to breaking the trust, which can potentially undermine the trust of the entire team.

Tip 7: Vulnerability

A common issue new leaders have, especially those who were excellent doers, is dealing with their own vulnerabilities. In the game industry, often a doer is evaluated by his or her individual capacity to generate code or assets. Leaders, on the other hand, are not evaluated only by their individuality: for this reason, even the best of the professionals or the most self-demanding one will inevitably have vulnerabilities, even if they come from one of the team members.

Still, it's far more usual for leaders to have their own vulnerabilities (Brown 2010). A common one for the newly hired or promoted is not being acknowledged as a leader by the team or some of the team members, usually the most senior ones. Another usual vulnerability is being simply less technically knowledgeable, if at all, than the team members.

It is of vital importance for the leader to correctly access the situation he or she is in and understand his or her vulnerabilities. More specifically, a leader should understand what he or she cannot do.

Either facing a limitation or struggling to avoid mistakes, the key element to take away is asking for help. The leader is not expected to know it all; he or she is not expected to be a super programmer or super artist. The leader is not expected to be able to solve all problems from a team. The leader is expected to care for the team and for the goals, and having help from others is the best way to do it.

A good way for a leader to access if he or she is doing properly on this topic is the feeling of being a fraud. A leader who feels he or she is a fraud is much more likely to access his or her vulnerabilities correctly. As the philosopher Socrates said: "All I know is that I know nothing."

Feeling as a fraud, of course, is not a necessary condition. But it's easy to feel like one when doing right. A good leader should not only care for his or

her team members to achieve their goals and, just as importantly, strive to grow the team members into becoming independent of him or her.

Having a team independent of the leader leads into his or her mind the natural questioning of how much he or she is needed by the company. Having this question in mind, while being well regarded by his or her peers or being able to repeatedly grow independent teams (just like being able to raise independent children), is a great sign for a leader.

Tip 8: Challenge

While a leader must inherently trust his or her team members, it is critical for the job to ascertain the right problems are being solved (Acton 2014). A common tool for this task is periodically checking what a team member is doing and challenging tasks when planning for them.

In order to maximize the chance of the priorities and plans being right, the leader can use a very important tool: asking questions (aka challenge). There are two main questions: What problem do we want to solve with a given task and why are we solving this problem?

While both questions are important, the "why" question is by far more relevant: a bad answer to a "why" might indicate that performing a given task is plain senseless. Going further, it happens quite often that questions in game development have several layers of complexity: to reach the primary reason why some tasks are required may need a series of "whys" asked on top of each other's contexts.

The idea behind this analysis is similar to the Socratic philosophy. Asking sufficient "whys" is a good way to understand where one knowledge ends and beliefs begin.

There is a risk into this approach, though: reaching a wrong conclusion. A reason for this to happen is that proving a decision is based on a belief makes it easy for someone to discredit an argument as most people want to make decisions seemingly based on reason.

Still, it's likely that most people will not apply the same technique on possible counterarguments. Also there is a good chance that the people the leader is talking to, especially if they are engineers, will have poor communication skills meaning that they won't be able to properly articulate the answer to the "whys" leading to an incorrect analysis. Apart from this, sometimes, people, for many reasons, will simply prefer not to verbalize some arguments.

One way to help in avoiding some of the risks of challenging arguments is, when possible, give people time to think about the questioning avoiding taking decisions during the challenging of an argument. This allows people to rethink about the answers they gave and improve their arguments.

The bottom line is: a good leader should challenge tasks and arguments but should understand that winning a discussion doesn't make the winner's ideas correct.

Tip 9: Commitment

Commitment is a key element in successful game projects (Acton 2014). Committed people tend to deliver work on time and with better quality. More often than not, therefore, successful teams are also committed teams: a good leader should foster this trait.

A key element on this context is having people agree on what should be done and, in many cases, how it should be done. An effective means to achieve it is letting the team decide by itself those two points: it's far easier to convince someone of his or her own ideas than of ideas coming from anyone else.

Obviously there are requirements for this idea to work: the team should be well informed of the sought objectives, it should not be formed only by juniors, and the leader should be ready to challenge the proposed plans. All of those elements, in most environments, are under control of the leader. A positive side effect of it is making them feel useful.

Once the agreement on what and how a plan should be done is reached, the proper scheduling of the tasks is another critical element to achieve commitment. If the team members consider a schedule unreasonable, they are likely to be right and unlikely to commit to it.

To support this argument, the people working in the game industry, no matter who is their leader, are often professionals. Sometimes they are even specialists on their craft. They are most likely better aware of their own capacity than anyone else. Going against it often justifies lack of commitment, as itself is often a lack of common sense.

Still, just planning with the team what should be done, how it should be done, when on time it should be done, and by whom it should be done is not enough to achieve proper commitment. A leader should also be ready to face a dire reality: intermediate steps of plans fail a lot. This often happens quite early in projects.

Delegating responsibilities over a plan's area to an individual or a group is the next step a leader can take into fostering commitment, especially on what regards fail contingency measures. Doing this, even when something unpredicted happens, people will understand who should solve it and the impact it will have on others: their primitive trust mechanism is more likely to trigger, generating commitment.

On the other hand, if plans are given to the team instead, they are much more likely to disagree upon its feasibility. People will feel forced instead of committed.

Tip 10: Vision

One of the important parts of the human mind is the desire to be part of something big: finding a meaning to a set of actions, something more than just surviving. It's no coincidence that religions can be very appealing: it's a human need.

A good leader should understand this aspect of human nature and help people fulfill their needs. Care should be taken, though, not to abuse it: most game companies won't want their employees blowing themselves, or at least ruining their personal lives, for the sake of their game.

The way for a good leader to work this aspect out is providing his or her team with the grand strategic vision behind the companies. In the game industry, the term "world domination" is often heard. Explaining how the company intends to achieve it and showing each team member's individual contribution for it is a great start. People will understand they have a future in the company doing so and are likely to stay longer (DeMarco and Lister 1999; Acton 2014).

There are some cases, though, where there is no grand strategy plan behind a company. Sometimes the company is looking for a new identity. It is conceivable to see this happening with one-hit studios, which often have a lot of money but don't know what to do with it. When this happens, an unusual opportunity takes place: the leader and his or her team have the chance to create a grand strategy for the company.

A common element of winning visions inside companies is market disruption. This can happen through new business or monetization models, new technology, inventing a new gameplay genre, finding an undersupplied niche, or reaching out for people who weren't previously gamers.

A good leader, therefore, should be ready to provide his or her team with the company vision. If none exists, he or she should create one.

Tip 11: Self-Improvement

Reality is simple: no one is perfect. Accept it.

The consequence of this affirmation is that all leaders can improve. A good one, therefore, should always work on improving himself or herself (Acton 2014).

There are several means to achieve self-improvement. A good leader will often try a few of them at a time. Still, among all the possibilities, one of them is mandatory: firsthand experience. Rarely anything will yield a deeper result than actually facing a challenge. Luckily this usually comes naturally as part of a leader's job; when it doesn't, though, this should be regarded as a warning sign and could be a reason to change jobs.

Most of the other means to achieve self-improvement gravitate around the sharing of experiences. Talking to other leaders and reading leadership-related texts can give the leader ideas about what to try when facing the challenges of this job.

Another category of actions is presenting one's experience. Once a leader finds him or her in a role

where he or she is expected to present his or her accumulated knowledge about leadership, this can be turned into an exceptional opportunity: change empiric information into systematic solidified knowledge.

Apart from that, a good leader should always be ready to listen. Sometimes all that is needed to solve a problem is a person in a different mind-set: a good leader will understand this and be happy to expand his or her own mind-set whenever confronted with a different one. Listening is a key element for it.

A good leader should also understand that he or she is often dealing with incomplete information, especially when it regards people. The result of it is that decisions which may seem obviously right can be the very opposite. Listening to people, especially the team members, is, therefore, a crucial element for improving a leader's capacity when regarding specific teams.

Finally, even more important for a leader than his or her own self-improvement is fostering this value for the team he or she leads. A good leader should not only be able to create a self-sufficient team but also a team capable of improving itself over time.

Tip 12: Yourself

Being a leader is hard. A leader is expected to always put the needs of the team above his or hers. This can be very taxing, as there is a single person having to care for many, having to worry about the results of many, having to worry even if their life outside work is going well.

A common mistake novice leaders do is succumbing to the sheer amount of things to care for and start having an unbalanced life. This is particularly true for the work/life balance.

The problem of this approach is that the less a person has a life outside work, the less this person will come refreshed to the office. This is a usual way through which stress builds up, and in the game industry this can be often perceived on crunch periods, particularly the longer ones.

When under stress, especially over longer periods of time, people tend to make poorer decisions. They tend to be less tolerant, be irritated over small things, and often overreacting. In the work environment, due to the power relations between the leader and the team, this can be disastrous. A good leader must always control his or her emotions. Emotional stability inspires trust on the people you lead.

It's, therefore, much easier to be a good leader when in a good state of mind. This requires the leader to take care of himself or herself. A happy leader is much more likely to be a good leader, and having a life outside work can be of great benefit for it.

Moreover, a great leader should go beyond merely the work/life balance. Having good relationships outside work is of immense help. This means that many of the things applied to be the leader of a team should apply to the people outside the office.

Above all, love should guide the relationships outside work with other people. Conflicts should be faced and resolved through communication (Stone et al. 2000), instead of endured.

There should be no fear in sincerely showing vulnerability (Brown 2010): trust people, but be ready to challenge any and all beliefs. Commit to goals and to other people, and be accountable for it (Acton 2014). Do so with a vision of yourself. And always seek self-improvement.

In the end life is complicated because we are always dealing with people: the same thing leaders have to deal with every day in their work.

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Game Editor

▶ Principle Structure to Create a 2D Game Level Editor

Game Engine

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Synonyms

2D Game Engines; 3D Game Engines; Particle system; Physics engine

Definitions

A game engine is a software package designed to simplify and accelerate game development. Game engines provide low-level functionality such as graphics rendering, game physics, and communication with input devices. This allows developers to focus on the actual content of the game: game logic, levels, and assets.

Overview

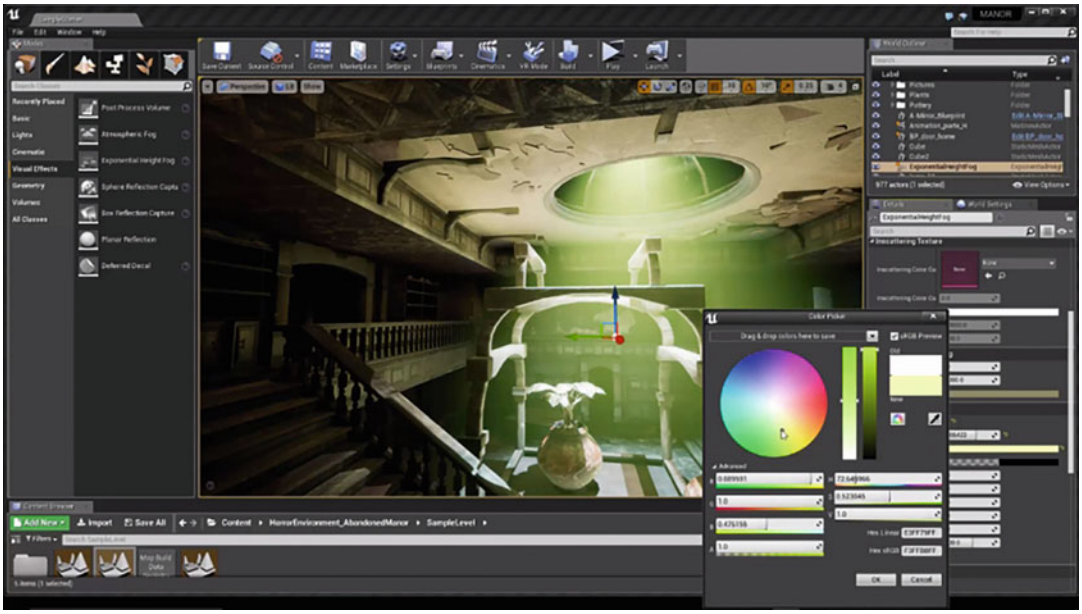
Game engines are based on the idea that a video game can be separated into two discrete layers: low-level "core" functionality and the "content" of the game proper, which, although built on top of the core, is essentially independent (Gregory 2009: 11–13). The "core" comprises basic operations which are indispensable to the game but do not directly constitute it, such as graphics rendering and sound playback, collision checking and in-game physics calculations, memory management and file operations, and so on. Delegating these stock routines to the game engine dramatically improves the efficiency of the development process, enabling the developer to focus on the manifest content of the game, such as, for example, its user interface, level design and physics of the game world, game logic and game mechanics, control scheme, etc. (Bishop et al. 1998).

A single game engine can also be reused in an indefinite number of games, which further streamlines the development process. Additionally, many modern game engines support multiple platforms, making it possible, for example, to use the same codebase to create a product for the personal computer, a game console, and mobile devices with minimal modifications.

Commercial-grade game engines are often geared toward a specific type of game. For example, id Software's *idTech* series of engines are specifically designed for use in first-person shooter games such as *Doom* (2016) and *Rage* (2011), while Telltale Games' eponymous *Telltale Tool* is intended for choice-driven adventure games with quick-time events. Engine specialization helps optimize resources and perfect the implementation of the particular features relevant for a given type of game: for example, skill trees and inventory management for role-playing games or graphics–audio synchronization for rhythm games. It also means that the choice of a game engine is a crucial decision: while the engine's workings may not be visible to the player, game engines can, through their functionality, "regulate individual videogames' artistic, cultural, and narrative expression".

Recent years, however, have seen a rise to popularity of more universal game engines such as *Unity* and *Unreal Engine*, whose functional range has gradually increased to the point where they can power most types of games. Even so, each game engine has its own set of characteristics and may be more or less suitable for particular tasks. For example, of the two engines mentioned above, *Unreal Engine* has more advanced graphical capabilities, while *Unity* is less computationally expensive and supports more platforms (Dickson et al. 2017).

While the term "game engine" in a narrow sense only designates a software infrastructure that powers a video game, many popular engines



Game Engine, Fig. 1 Like many modern game engines, Unreal Engine includes a scene editor and an integrated development environment

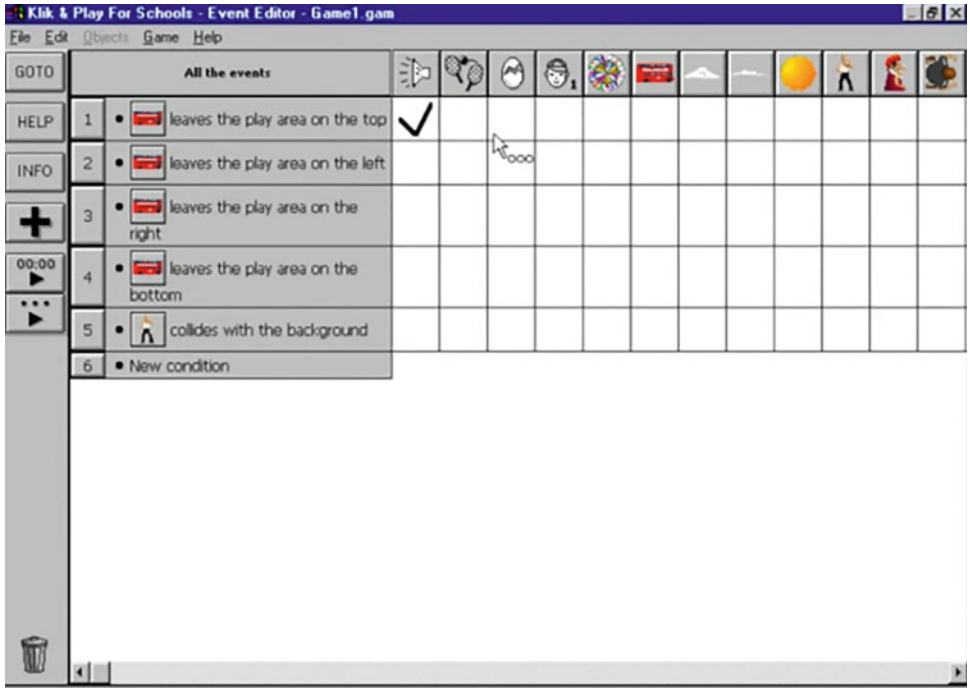
bundle with an integrated development environment, allowing developers to code the game in the same software ecosystem where it is tested. It is also common for a game engine to come with a level editor and sometimes a user interface editor, as is the case for *Unreal Engine* and *Torque 3D*. Some game engines, such as *Unity* and *GameMaker*, also support add-ons and plugins, making it possible to extend their out-of-the-box functionality with third-party solutions (Fig. 1).

History

In the early days of gaming, video games were often programmed from scratch (Bishop et al. 1998). However, the increasing complexity of the video game medium, the evolution of software and hardware, and the advent of the multi-million-dollar game industry with its pressure on cost and efficiency have made this approach unsustainable in commercial game development. Code was increasingly recycled and dedicated libraries were created to deal with low-level operations like graphics rendering.

The desire to further optimize the development process eventually led to the emergence of the game engine. One of the earliest examples is Infocom's Z-machine, a virtual computer created in 1979 which executed commands in its own language, specifically tailored for interactive fiction games such as *Zork*. The use of a virtual machine helped Infocom avoid developing separately for the multitude of home computer architectures that were in use at the time (Bartholomew 2008).

In 1984, Sierra On-Line released *King's Quest: Quest for the Crown*, the first game based on Sierra's own *Adventure Game Interpreter* (AGI). Initially, AGI was created because Sierra felt that an easier, tailor-made engine would allow writers and designers to work more independently from programmers, thus benefiting the workflow (Loguidice and Barton 2012: 150). The company ended up using AGI in 14 different adventure games before switching to the more advanced Sierra Creative Interpreter in 1988. By that time,


Klik & Play For Schools - Event Editor - Game1.gam
File Edit Objects Game Help
GOTO
HELP
INFO
00:00
All the events
1 leaves the play area on the top
2 leaves the play area on the left
3 leaves the play area on the right
4 leaves the play area on the bottom
5 collides with the background
6 New condition

Game Engine, Fig. 2 Ultima Underworld (1992) was one of the first games based on a 3D game engine

Sierra's competitor *LucasArts* was using its own custom engine SCUMM to create point-and-click adventure games (Black 2012).

The early 1990s oversaw the emergence of 3D game engines. A notable early example is the engine used in *Ultima Underworld* (1992), which was partially based on the basic 3D rendering engine of *Space Rogue* (1989), but was much more advanced, adding the use of texture mapping (Paul et al. 2012). In the same year, id Software released *Wolfenstein 3D*, a pioneering first-person shooter, also powered by an engine from an earlier game (*Hovertank 3D*) with the addition of texture mapping and ray casting. Following the success of *Wolfenstein 3D,* id Software set an important precedent by licensing the game engine to other companies who then produced such titles as *Blake Stone: Aliens of Gold* (1993) and *Super 3D Noah's Ark* (1994). This heralded the era of third-party engine licensing, where the use of an in-house game engine was no longer inevitable. Id Software in particular continued licensing the engines for its subsequent titles such as *Doom* (1993) and *Quake* (1996) to other developers. In addition, first-person shooters' growing popularity demanded increasing technological innovation, with each major title expected to be more advanced than the previous one, thus necessitating a more sophisticated engine. As a result, first-person shooters "played a fundamental role in founding the industry of game engines" in the 1990s (Fig. 2).

Another significant development was the emergence of consumer-grade game engines, aimed at hobbyist game creators with little expertise in programming. Clickteam's *Klik & Play*, released in 1994, was an important early game engine which was easy to use, had an integrated event and level editor, and relied on solely visual coding (Djaouti et al. 2010). It was followed by other engines, such as *GameMaker* and *Construct*, as well as technologies such as

Game Engine, Fig. 3 Klik & Play (1994) was a pioneering consumer-grade game engine

Macromedia Flash, which have empowered enthusiasts with little technical knowledge to make their own games (Fig. 3).

Conclusion

Game engines have changed the logic of video game development, introducing a more efficient, content-centered approach and simplifying the production of multiplatform content. The appearance of consumer-grade engines and the easy availability of professional solutions such as *Unity* and *Unreal Engine*, coupled with the advent of Web 2.0, has also significantly lowered the entry barrier to game development. Despite some popular engines positioning themselves as universal, the choice of an engine is still a crucial decision which can have much influence on the development process and its outcome.

Cross-References

- ▶ Game Physics Engine, Overview
- ▶ Panda3D
- ▶ Unity, a 2D and 3D Game Engine
- ▶ Unreal Engine, a 3D Game Engine

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Game Engine Loop

► Game Loop and Typical Implementation

Game Engine Main Loop

► Game Loop and Typical Implementation

Game Engine Update Loop

► Game Loop and Typical Implementation

Game Engines

► Virtual Reality Game Engines

Game Integrity Validation

► Secure Gaming: Cheat-Resistant Protocols and Game History Validation

Game Interface: Influence of Diegese Theory on the User Experience

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Synonyms

Diegetic interfaces; Graphical interface; HUD (heads-up display); Human-computer interaction

Definitions

User experience (UX) is the set of elements and factors related to the interaction of the user with a particular product, system, or service whose result generates a positive or negative perception.

The game interface is fundamental for the player experience once transmits information such as life and/or power bars, stopwatches, inventory, punctuation, etc. This information is referenced by heads-up display (HUDs).

Diegese refers to the world in which the events of a story occur, defining what makes or does not part of the virtual scenario and what is visible to the characters that inhabit this alternative universe.

Introduction

The user experience (UX) is the set of elements and factors related to the user interaction with a particular product, system, or service whose result generates a positive or negative perception. When

interacting with a product, people seek new experiences through perceptions that involve practical and subjective aspects such as usability, efficiency, and satisfaction. Beyond subjective, UX is dynamic since changes over time due to the presentation of new challenges and rewards (Hassenzahl and Tractinsky 2006; Schell 2008; Garrett 2010; ISO 9241-210, 2010; Costa and Nakamura 2015).

According to Russell (2011), the interface design is often one of the most challenging aspects of game design. This fact occurs because there is a great amount of information to transmit to the player in relation to the screen space available. If this relationship is not balanced correctly, the user experience with the game can be frustrating. Other elements that also directly influence the perception of the interface by the user are color and composition concepts (Ware 2008).

Game interfaces are usually composed of two main elements: (1) controls common to other computer systems, such as buttons and menus and (2) heads-up display (HUD), which refer to graphic elements present on the game interface that transmit information to the user. The integration of the HUD components and the game world influence the immersion of the user experience and interaction.

In this sense, the HUDs can be displayed in a traditional way or incorporated into the universe of the game, in order to offer immersion to the player and, consequently, a more concrete experience. In this sense, a rereading of the diegese theory can be done for the definition of HUDs, breaking with traditional paradigms of graphical interfaces in games. Two main aspects are part of the theory of diegese: the narrative and the fourth wall (Genette 1980; Rohden et al. 2011).

This entry discusses concepts of diegese theory in the scope of design and development of graphical interfaces for games. We relate the elements of the narrative and the fourth wall to the experience provided to the player, comparing the different forms of HUD presentation during the evolution of digital games. Diegetic and nondiegetic elements, especially in HUD, are discussed in order to clarify how these relate to the transposition of the fourth wall as a strategy to achieve the projected user experience.

The text is organized as follows. Section "Games and Diegese Theory" addresses the main issues related to diegese applied to the game interfaces. Section "Applying Diegetic and Nondiegetic Interfaces in the Game Design" presents a discussion of the concepts presented in section "Games and Diegese Theory," and finally, section "Conclusions" presents the final considerations.

Games and Diegese Theory

Considering the user experience in games, the graphical interface should be constructed in order to provide the communication between gameplay objects and the player. Among different studies involving games interaction, Fagerholt and Lorentzon (2009) suggest the use of diegese theory, adapted from the areas of literature, cinema, and theater.

In game design area, the diegese refers to the game universe, defining what is or is not part of the virtual world, and is based on two main principles: the narrative and the fourth wall. The narrative is related to the game story (fictitious world). Besides, the fourth wall deals with the imaginary division between the player and the game world. For the player to immerse himself in the game world, he must pass through the fourth wall.

The player's ability to move between the real world and the game world depends on how the interface designer provides information for him. In this sense, the HUD elements are considered diegetic if they are part of the universe of the game and the characters are aware of these elements. Thus, the HUDs must communicate something understandable to the characters according to events and rules defined in the universe. In some cases, the characters will interact directly with these elements and, eventually, these can exist exclusively to communicate something, not being functional.

The game Dead Space (Electronic Arts Inc. 2018a) is an example that employs the

Game Interface: Influence of Diegese Theory on the User Experience, Fig. 1 Dead Space game (Electronic Arts Inc. 2018a)

concept of diegetic interface. As shown in Fig. 1, attached to the character's armor is a luminous marker that represents his life bar. This element visibly is part of the universe of the game, being present along with the main character, that is, it is not an element that only the player can visualize, but any character of the game universe.

The integration of diegetic elements into the game universe is considerably relevant to creating the projected experience – not only in relation to the interface but also to the game in general. If a diegetic element escapes the context of the universe, this can generate a noise (Schell, 2008) in the player's experience, which potentiates the opposite effect in relation to the goal of diegese in games, which is to increase the immersion and quality of the experience. Thus, diegetic interfaces require a work of harmonization with the elements of the game, in order to transpose the fourth wall in the proper way (Rohden 2011; Russel et al. 2011).

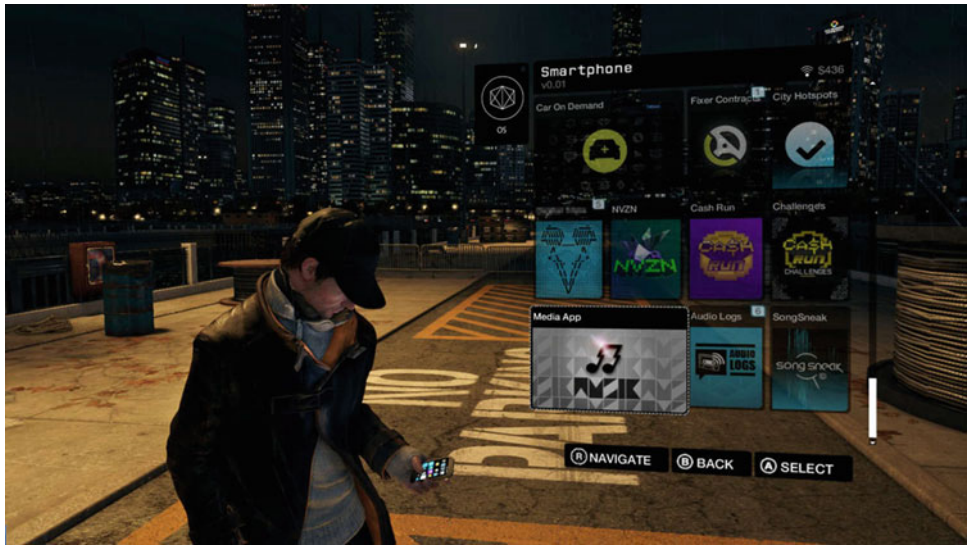
Unlike diegese theory, nondiegetic interfaces are defined as being outside the game universe. The use of nondiegetic HUDs was initially recurrent in the gaming industry and this fact led in some cases to an increase in the insertion of graphic elements, polluting the game interface (Fig. 2). This practice contradicting the idea that only the essential elements should be displayed in an interface (Hassenzahl and Tractinsky 2006; ISO 9241–210 2010; Garrett, 2010). With game industry maturity, diegetic interfaces began to gain space.

Besides diegetic and nondiegetic HUDs, Fagerholt and Lorentzon (2009) propose two other types: spatial and meta. The concept of spatial HUDs is applied when a certain element is present in the 3D space of the game, but it is not part of the universe, nor can the characters see it. In general, these interface elements are used to indicate avatars selected or other indicators. In the game The Sims 4, for example, in addition to nondiegetic elements, some elements with the spatial approach are employed. Figure 3 shows a character, positioned to the right in the image, which is accompanied by a spatial interface element (the balloon).

On the other hand, meta elements are part of the game universe but not necessarily in the 3D plane. In general, meta elements are used as applied effects on the game camera, such as blood dripping from being hit by a shot (as well as other types of damage), or effects of rain particles, solar reflection among others. The Watch Dogs game (Ubisoft Entertainment 2017a) is an example of using HUDs meta with the transposition of the elements of the game universe, which causes the fourth wall to be crossed by the player (Fig. 4). Therefore, during the use of the smartphone of the character, the screen is presented to the player as a nondiegetic element.

Game Interface: Influence of Diegese Theory on the User Experience, Fig. 2 NDI HUDs of World of Warcraft game (Blizzard Entertainment, Inc., 2018)

Game Interface: Influence of Diegese Theory on the User Experience, Fig. 3 The Sims game (Electronic Arts Inc. 2018b)



Game Interface: Influence of Diegese Theory on the User Experience, Fig. 4 Watch Dogs game (Ubisoft Entertainment 2017a)

These four types of HUD discussed in this section can be combined to allow an effective immersion of the user in the game universe, enhancing their experience with the game.

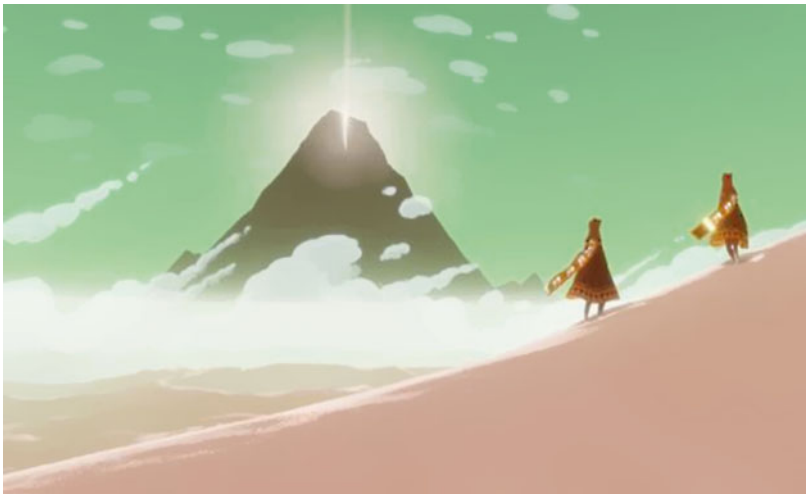
Applying Diegetic and Nondiegetic Interfaces in the Game Design

This section focuses on the discussion of the main aspects related to the design of HUDs in game interfaces based on diegese theory. Thus, some questions that can help the HUD project are listed, seeking to perform a critical analysis situated in the current scenario of games and based on the research carried out in this work:

1. *What are the main advantages of DIs?*
2. *What is the motivation for using DIs?*
3. *Is there any kind of idea that only works in DI?*
4. *Are NDIs still required to achieve the required level of gameplay?*
5. *Can DIs make use of non-diegetic elements in their design?*
6. *What is the tolerance for excess HUDs in NDIs? Is it possible to improve this issue with the free customization of HUDs over the interface?*
7. *Does the game depend on immersion?*
8. *What is the relationship between aesthetics, complexity and gameplay in games?*

Regarding question 1, it is noted that some game genres can improve their immersion with the use of DIs, which help keep the player's attention within the game world. Some games, by their simple nature, do not even need an interface; others, that are not dependent on a large number of mechanics, can use some part of the avatar itself to give feedback to the player, such as the Journey avatars (Sony Computer Entertainment America LLC 2014a; thatgamecompany 2018a, Fig. 5) and the Dead Space avatar armor (Fig. 1), which mask use of a status bar.

Concerning question 2, with the beginning of the popularity of independent games (indie games) in the middle of the seventh generation of consoles, some games present the intention to stand out in a market long structured and dominated by large companies that focused on HUDs based on NDIs. However, the use of DIs represented an innovation, since the use of creativity was the only resource for small gaming companies to gain prominence in this market. Thus, new games, especially so-called art games,



Game Interface: Influence of Diegese Theory on the User Experience, Fig. 5 Journey game (Sony Computer Entertainment America LLC 2014a; thatgamecompany 2018a)

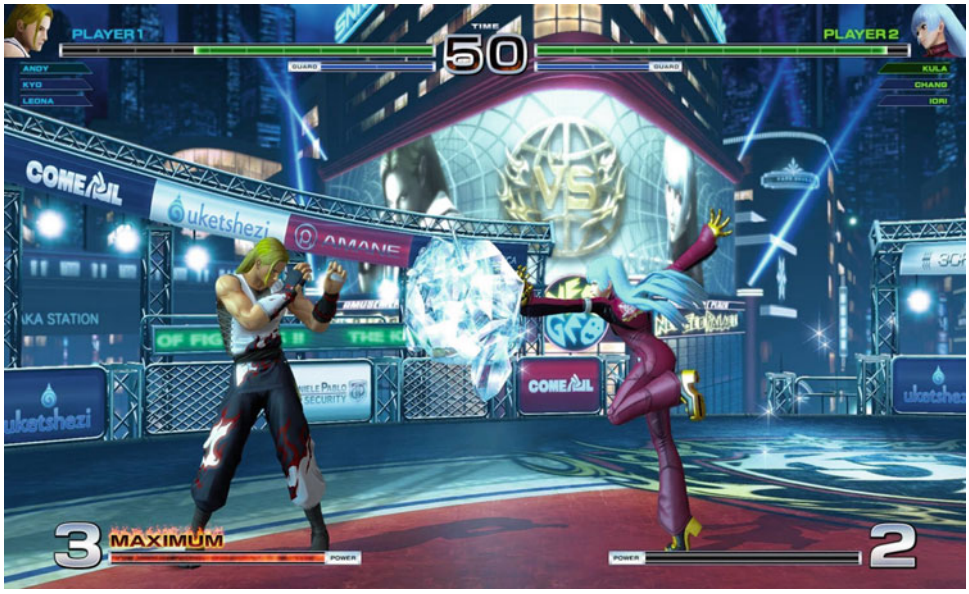
Game Interface: Influence of Diegese Theory on the User Experience, Fig. 6 Flowe game (Sony Computer Entertainment America LLC 2014b; thatgamecompany 2018b)

explore DI integrated in a natural and functional way to game design. The game Flower (Sony Computer Entertainment America LLC 2014b) (thatgamecompany 2018b) (Fig. 6), for example, was one of the first indie games to become popular in the market and to present an innovative interface concept and user experience.

The Journey and Flower games proposals are examples of experiments based on DIs (question 3) and probably would not reach their level of immersion with the use of NDIs. The concepts of these games can only be demonstrated with elements of HUD inserted in the universe, in order to give the player the information and the notion he needs. In this sense, the game Firewatch (Campo Santo, 2018) is another example where the DI is fundamental, because, instead of an NDI with a map containing arrows that aim their objectives, the player has only a map and a compass and must be guided by its own reasoning (Fig. 7).

Regarding question 4, in game genres where the player needs accurate information, usually in numerical form or through bars, NDIs are still the best form of HUD. In the King of Fighters series (SNK Corporation, 2018) (Fig. 8), for example, each millimeter of the bar makes a significant difference for the player to plan attacks on the enemy. In fighting games, hardly an element of identification would be as precise and with communication as clear as the bars of life. One

Game Interface: Influence of Diegese Theory on the User Experience, Fig. 7 Firewatch game (Campo Santo, 2018)



Game Interface: Influence of Diegese Theory on the User Experience, Fig. 8 King of Fighter game (SNK Corporation, 2018)

possibility in this type of game would be to demonstrate how close the character is to being defeated by his body wounds. In fact, several games have used this feature, but it does not meet the need of the life bar. This is an example of how NDI is still needed and cannot always be replaced.

In relation to question 5, the game Dead Space (Fig. 2) can be considered an example of ID that makes use of the style of NDI, incorporating the latter to the universe of the game. For example, status bars and menus are displayed as screens within the game universe in a futuristic way. The Far Cry 2 game (Ubisoft Entertainment 2017b)

Game Interface: Influence of Diegese Theory on the User Experience, Fig. 9 DI presenting information in the form of NDI in Far Cry game (Ubisoft Entertainment 2017b)

(Fig. 9) is another example that mixes concepts of NDIs and DIs on the same screen. Although most HUDs follow the concepts of DIs, information such as ammunition, opportunities for interaction, and health are displayed as a message in the format of NDI on the screen. In the same context, Team Fortress 2 game (Valve Corporation, 2018) presents spatial elements in addition to diegetic and nondiegetic elements (Fig. 10).

Considering question 6, it is observed that the amount of HUDs in NDIs is directly proportional to the game complexity. In some cases, a large amount of HUDs is unavoidable for the desired gameplay, such as the World of Warcraft game (Fig. 2). On the other hand, the possibility of interface customization helps the player to create an identity with the game, allowing the adaptation of the HUD positions according to their needs and preferences (Preece et al., 2005). This feature is especially important when the game interface has many types of HUDs.

The question 7 addresses gameplay versus immersion. In this sense, it must be considered that the focus of the player is on the gameplay. However, gameplay and immersion can go hand in hand in order to enhance the player experience. Aragão (2016), for example, states that the issue of immersion in the fictional environment of the game is inseparable from the gameplay. Some indie games exploit this relationship, breaking conventional paradigms of games through an abstract experience related to exploration and discovery as in the Hohokum game (Sony Computer Entertainment America LLC 2014c; Honeyslug Ltd., 2011) (Fig. 11).

Finally, regarding question 8, it should be considered that it is possible to play a fun game with an underdeveloped narrative and an unpleasant aesthetic, but it is difficult to play a game with good aesthetics if the experience it offers is not satisfactory. The concept of gameplay, however, is extensive and even a game that offers little complexity does not necessarily become an inferior game. Such games can abdicate the complexity for a game that focuses on aesthetics, as long as the gameplay does not suffer any kind of commitment. Sound Shapes game (Sony Computer Entertainment America LLC 2012, Fig. 12) is an example that had significant success in the gaming industry.

After analyzing the eight questions raised in this section, is noticed the type of HUD to be employed in a game depends on some key elements:

- Player/user experience
- Immersion level
- Narrative

Game Interface: Influence of Diegese Theory on the User Experience,

Fig. 10 Team Fortress 2 game (Valve Corporation, 2018): (**a**) Spatial elements; (**b**) diegetic and nondiegetic HUDs

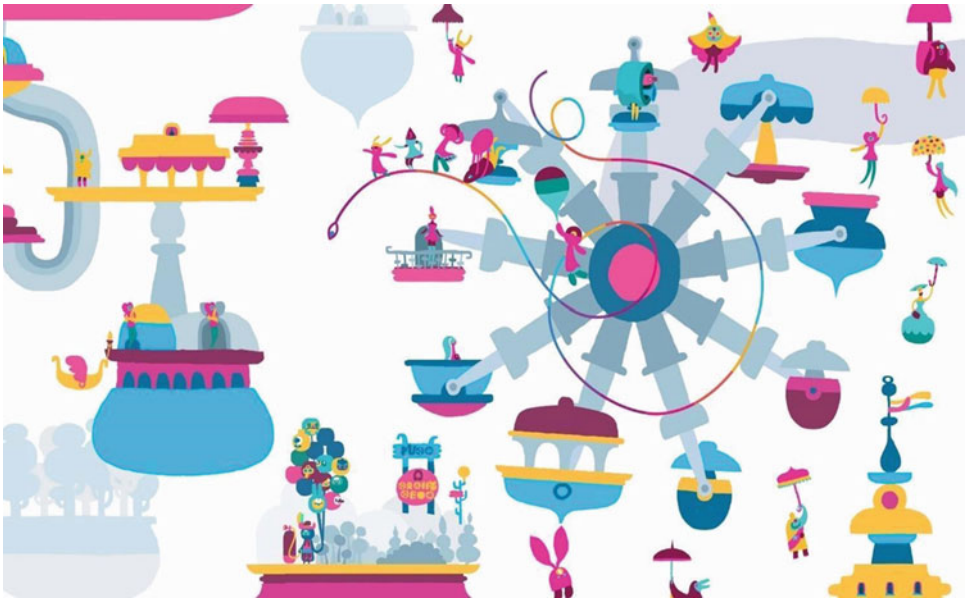
- Aesthetics
- Style
- Target audience
- Complexity of mechanics
- Feedback

Issues related to the definition of DI or NDI should take into account these listed aspects, since the gameplay and usability depends on the level of accuracy of the information related to the mechanics of the game. Moreover, some studies have been carried out in order to analyze the preference of users for diegetic or nondiegetic interfaces as well as to assess the accuracy of diegese design for games (Fagerholt and Lorentzon 2009; Iacovides et al. 2015; Peacocke et al. 2015). Is noticed that diegetic interfaces positively impact the user experience, increasing immersion, cognitive involvement, and a sense of control. However, the user experience also depends on the player's level of expertise and game genre.

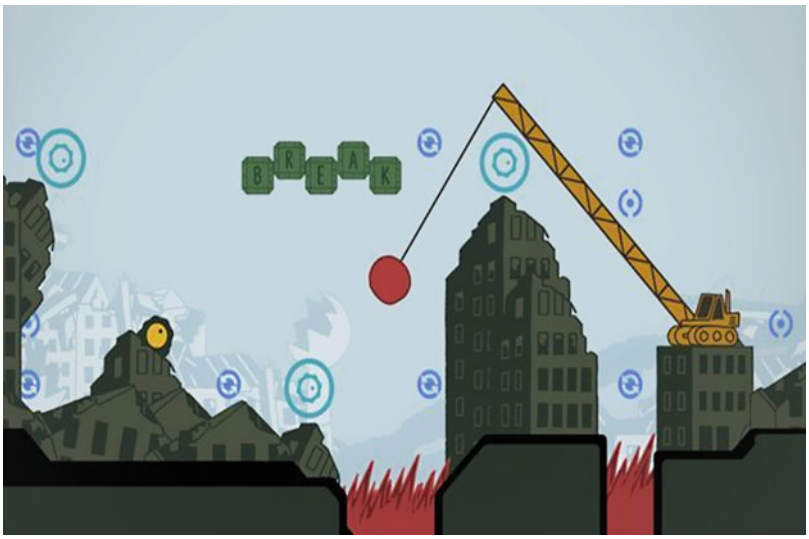
Conclusions

The evolution of the gameplay changes the way the player interacts with the game, having different forms of HUDs and feedbacks. Most games with diegetic interface end up being natural enough that the player does not realize that he crossed the whole adventure without using a conventional nondiegetic interface. On the other hand, the increasing complexity of the games is directly related to the demand for nondiegetic interfaces, due to their greater precision in the display of information.

The understanding of the diegetic and nondiegetic interfaces presented in this work can



Game Interface: Influence of Diegese Theory on the User Experience, Fig. 11 Honokum game (Sony Computer Entertainment America LLC 2014c; Honeyslug Ltd., 2011)



Game Interface: Influence of Diegese Theory on the User Experience, Fig. 12 Sound Shapes game (Sony Computer Entertainment America LLC 2012)

collaborate for the best quality in interfaces design. However, there is no interface approach that will always be the most appropriate, just as in some cases the combination of different approaches can foster the construction of a more consistent HUD.

Cross-References

- ▶ Cognitive Psychology Applied to User Experience in Video Games
- ▶ Pervasive Games

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Game Level Design

▶ Principle Structure to Create a 2D Game Level Editor

Game Level Editor

▶ Decoupling Game Tool GUIs from Core Editing Operations

Game Loop and Typical Implementation

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Synonyms

Game engine loop; Game engine main loop; Game engine update loop

Definitions

At the innermost core of every game engine is a compact infinite loop. This loop continuously iterates through the steps of receiving and processing player input, updating the entire game state, and rendering and displaying the game objects. This loop is executed at a short but discretised time interval supporting seemingly instantaneous interactions between the players' input and the graphical gaming elements. This constantly running loop is referred to as the game loop.

Introduction

To convey a lifelike sense of instantaneity, each cycle of the game loop must be completed within a normal human's reaction time. This is often referred to as real time: the amount of time that is too short for humans to perceive both visually and cognitively. Typically, real-time can be achieved when the game loop is running at a rate of at least 40–60 cycles in a second. The speed of a standard game loop, with one drawing operation per cycle, can be quantified as the number of drawn frames per second (FPS), commonly called the frame rate.

An FPS of 60 is a good target for performance. At such a frame rate, update of the screen will coincide with a game update. This synchronicity increases the fluidity of motion and reduces the perception of the graphics lagging or appearing jittery. This is to say, your game must receive player input, update the game world, and then draw the visual elements of the game world all within 1/60th of a second.

The game loop itself, including the implementation details, is one of the most fundamental control structures of a video game. With the main goal of maintaining real-time performance, the details of a game loop's operation are of no concern to the rest of the game. For this reason, the implementation of a game loop should be tightly encapsulated in the core of the video game with its details hidden from other operations and gaming elements.

Typical Game Loop Implementation

A game loop is the mechanism through which the in-game logic and drawing of visible elements are continuously executed and presented. A simple game loop consists of processing the input, updating the state of game objects, and drawing those objects, as illustrated in the following pseudocode:

```
initialize();
    // Initialize the game state
while(game running) {
  input();
       // Receive input from the user
  update();
       // Iterate through and update
          every game object
  draw();
       // Render and display all visual
          elements
}
```

As discussed, an FPS of 60 is required to maintain the sense of real-time interactivity. When the game complexity increases, one problem that may arise is that sometimes a single loop can take longer than 1/60th of a second to complete. When this happens, a game would have to run at a reduced frame rate and the entire game will appear to slow down. A common solution is to prioritize which operations to emphasize and which to skip. Because correct input and updates are required for a game to function as designed, the draw operation is often the one that is skipped when necessary. This is known as frame skipping, and the following pseudocode illustrates one such implementation:

```
elapsedTime = now;
    // Time for one loop cycle
previousLoop = now;
    // Begin of previous cycle
while(game running) {
    elapsedTime += now - previousLoop;
       // Time for previous cycle
    previousLoop = now;

    input();
       // Receive player input
    while( elapsedTime >=
      UPDATE_INTERVAL ) {
```

```
        // if previous cycle took too
           much time
        update();
            // Ensure game is up to date
        elapsedTime -= UPDATE_INTERVAL;
    }
    draw(); // Draw the updated game
}
```

In the pseudocode above: UPDATE_INTERVAL is the maximum time allowed for one game loop cycle. When the elapsed time between completed game loop cycles is greater than the UPDATE_INTERVAL, the update() function will be continuously called until the actual game state is caught up. This means that the input() and draw() operations are essentially skipped when the game loop is running too slowly. When this happens, the entire game will appear to run slowly, with lagging player input responses and frames skipped. However, the game logic and state will continue to be correct.

Notice that the while loop that encompasses the update() function call simulates a fixed update time step of UPDATE_INTERVAL. This fixed time step update allows for a straightforward implementation in maintaining a deterministic game state.

Cross-References

- ▶ Character Animation Scripting Environment
- ▶ Decoupling Game Tool GUIs from Core Editing Operations
- ▶ Game Engine
- ▶ Game Physics Engine, Overview
- ▶ Physical, Virtual, and Game World Persistence

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Game Mechanics

▶ Gamification of Modern Society: Digital Media's Influence on Current Social Practices

Game Performance

▶ Online Gaming Scalability

Game Physics

▶ Game Physics Engine, Overview

Game Physics Engine

▶ Unity, a 2D and 3D Game Engine
▶ Unreal Engine, a 3D Game Engine

Game Physics Engine, Overview

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Synonyms

Game physics system; Game physics; Physics engine; Rigid body physics

Definitions

A game physics engine is a self-contained subsystem of a game engine which defines the physical characteristics of objects in the game world. The subsystem is typically utilized to simulate and approximate lifelike interactions between game

objects. A game physics engine may not be present in all game engines, but when one is defined, it operates on simple geometric shapes and is only invoked when necessary. This is because the simulation of physical interactions is computationally costly and typically only a selective subset of objects in the game world would define physics components and participate in the simulation.

Introduction

Game object interactions that mimic real life have become a key element of many modern PC and console games as well as, more recently, browser and smartphone games. For example, when shooting a basketball in a video game, the player would expect the ball's trajectory and interactions with the backboard and hoop to resemble the physical world. An effective way of conveying real world object behaviors is by approximating and simulating the underlying physics based on a game physics engine subsystem.

A Rigid Body Game Physics Engine

The range of topics within physics for games is broad and includes, but is not limited to, areas such as rigid body, soft body, fluid, and particles. Rigid bodies are objects that do not change shape. For example: a Lego block, your desk, or the hardwood floor. The interactions between rigid bodies, for example, a falling Lego block bouncing off your desk and landing on the hardwood floor, are best understood scientifically and thus most straightforward to simulate computationally.

Rigid body simulation approximates many types of object interactions in video games and is the core of most game physics engines. A rigid body game physics engine defines rigid shapes to serve as the components of objects in the game world. At runtime, during each game loop update cycle, the game physics engine would iterate through all defined rigid shapes and:

1. Calculate the motion of the shapes and move them
2. Detect collisions between the shapes, if present
3. Resolve potential interpenetrations between the colliding shapes
4. Compute proper responses for the colliding shapes

The proper implementation of these simulation steps enables believable scenarios when objects physically interact with each other in the game world.

Efficiency Considerations

The computation involved in detecting and resolving collisions between arbitrary rigid shapes can be algorithmically complicated and computationally costly. Most rigid body game physics engine implements two optimizations to address these challenges: *simple shape approximation* and *selective computation*.

Simple shape approximation. Rigid body simulations are typically based on a limited set of simple geometric shapes. For example: rigid spheres, rectangular boxes, and cylinders. In most game engines, these simple rigid shapes can be attached to geometrically complex game objects for approximating their physical behaviors. For example, attaching rigid spheres on the hands of a basketball shooter and using the rigid body physics simulation of the rigid spheres to approximate the physical interactions between the hands and the basketball.

Selective computation. To avoid excessive runtime complexity and resource demands, physics simulation are only carried out for essential game objects. For the basketball game example, while it may be important to model and simulate the physical interactions between the basketball and the hands of the in-game characters, such computations would be unnecessary between other nonessential objects like the basketball and the heads of the characters. To facilitate the selective invocation of computation on only a designated subset of game objects, physics representation and computation simulation are usually abstracted and structured as an independent subsystem within the game engine.

The Context of Entity-Component-System Pattern

Referencing the entity-component-system (ECS) pattern, all objects in the game world are components with only a selective subset having a corresponding physics component defined. The game physics engine simulation only involves the physics components. It is important to recognize that a physics component only attempts to approximate the physical properties of a game object for interaction purposes and that the component typically cannot be used to represent the game object in general as it lacks fine detail. For example, a rigid sphere may be defined as the physics component of a basketball game object. A more striking example would be the in-game character's hands which are likely to be represented by detailed 3D models while the physics components of these objects may be a collection of simple rigid spheres and cylinders.

Cross-References

- ▶ Game Engine
- ▶ Game Loop and Typical Implementation

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Game Physics System

- ▶ Game Physics Engine, Overview

Game Platforms

- ▶ Game Venues and Platforms

Game Player Modeling

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Synonyms

Player modeling; Preference modeling

Definition

Game player modeling is the study of computational models to gain an abstracted description of players in games. This description helps to detect, predict, and express the behavior and feelings of players and personalizes games to their preferences.

Introduction

Game player modeling is the study of computational models to gain an abstracted description of players in games. This description helps to detect, predict, and express the behavior and feelings of players and personalizes games to their preferences. These models can be automatically created using computational and artificial intelligence techniques which are often enhanced based on the theories derived from human interaction with the games (Yannakakis et al. 2013). It offers two major benefits. First, it helps in content customization to cover broader range of players with different skill levels and adapt challenges on the fly in response to the player's actions (Bakkes et al. 2012). Second, it works as a form of feedback for the game developers and designers so that they may add new innovative features to the games as well as develop new games that advance knowledge, synthesize experience, and escalate the interest of the player (Yannakakis et al. 2013).

The very first instance of research on player modeling was reported in the 1970s where Slagle

and Dixon attempted to model the behavior of opponent players in the domain of classical games by assuming the elementary fallibility of the opponent (Slagle and Dixon 1970). Later on, a search method based on knowledge about opponent players (i.e., strengths/weaknesses) was invented in 1993 (Carmel et al. 1993). In 2000, Donkers improved opponent modeling by taking into account the computer player's uncertainty (Donkers 2003). Afterward, an increasing interest developed in the player modeling of modern video games to raise the entertainment factor (Charles and Black 2004). Recently, player modeling has extrapolated its perspective from opponent modeling to a number of other research topics including player satisfaction (Yannakakis 2008), modeling player's preferences (Spronck and Teuling 2010), runtime challenge adaptation (Yannakakis et al. 2013), playing style, and learning effective game strategies (Lockett et al. 2007). A comprehensive history of player modeling is given in (Bakkes et al. 2012).

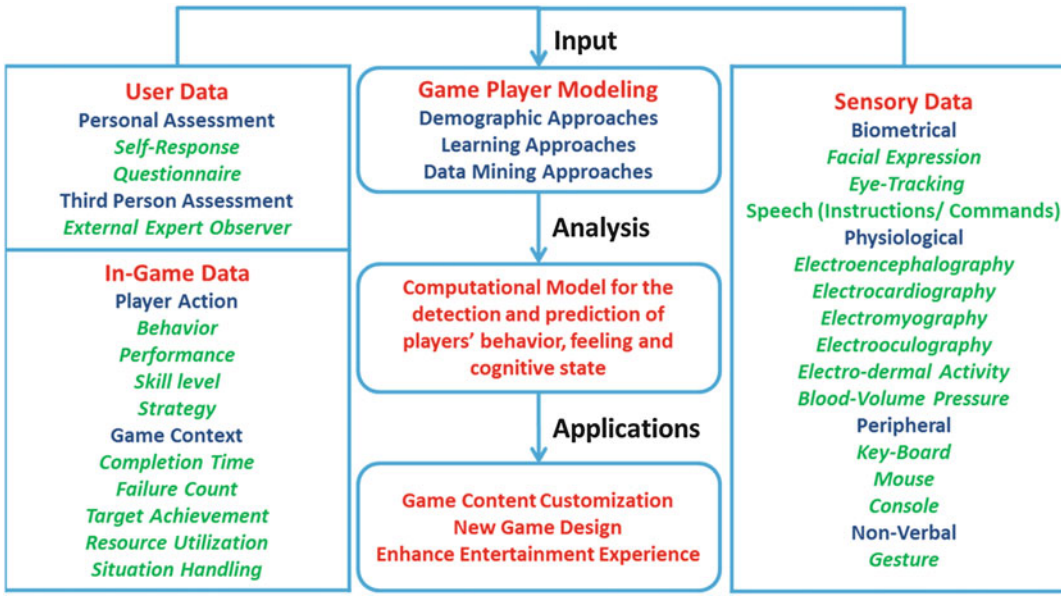
A player model can have three types of inputs: user data, sensory data, and in-game data (Yannakakis et al. 2013; Martinez and Shichuan 2012). User data includes personal assessment and third-person observation. The negligible limitations of user data are non-relevant data assessments, short-time memory, and player's self-deception (Yannakakis 2012). Sensory data includes data collected from the sensors mounted on the player's body or in the player's surroundings. The most common sensor data includes biometrical (Gunes and Piccardi 2006), physiological (Drachen et al. 2010; Martinez et al. 2013), peripheral (Omar and Ali 2011), and nonverbal natural user interface with the games (Amelynck et al. 2012). However, the sensor's interface with the player faces challenges when it comes to accuracy and performance. In-game data is based on the player's actions taken within the game to infer performance, skills, strategies, behavior, and game contexts including level completion time, mission failure counts, resource utilization, situation handling, and target achievements (Nachbar 2013; Kim et al. 2012; Weber et al. 2011). The big challenge is to interpret the raw data correctly for high-level player modeling using limited amount of data.

Based on the type of the input data, several learning and data mining approaches are used for player modeling as can be seen in Table 1. The effectiveness of the modeling technique based on user data is calculated using demographic/stereotype approaches (Butler et al. 2010). The major challenge in such models is that they are limited to deal with situations where individuals greatly deviate from the average. The sensory data is correlated to the player's behavior, emotions, preferences, cognitive, and affective states (Drachen et al. 2009). Physiological signals are correlated to arousal and valance using Plutchik's emotion wheel and the valence-arousal scale by Russell (1980), facial expressions using continuous, categorical, and active appearance models, speech or psycholinguistic narrations using PERSONAGE, and psychological factors using Big Five model (Lankveld 2013). In-game data features collected during the game play are used to identify or predict the type of the players which can then be further used for personalized component generation or level modifications (Drachen et al. 2009). An overview of input data gathering, modeling approaches, computational analysis, and applications of game player modeling is shown in Fig. 1.

Although a lot of work has been done on the player modeling, several remaining issues need to be addressed. For instance, sensory data-based models lack non-obtrusive data assessment, data reliability, data validity, vigilance recognition, and quick reactivity. User data-based models exhibit low correlation with the data collection time and the particular situation. In-game data-based models are restricted to particular players' personal interests in game, expert level, mood, enthusiasm, and surrounding environment, making it difficult to generalize for all players. However the generalization problem is resolved by continuously comparing and adjusting procedural personal behavior with human behavior and active player modeling (Holmgard et al. 2014; Togelius et al. 2014). Furthermore, hybrid approaches are used to overcome the issues of individual data-based player models (Arapakis et al. 2009;

Game Player Modeling, Table 1 Techniques used for game player modeling based on the input data types

Data type	Techniques		
	Supervised learning	Unsupervised learning	Other
User data	Supervised learning (shaker et al. 2010)	Probabilistic learning (Togelius et al. 2014)	Rating-based approach (Mandryk et al. 2006)
	Neural network (Schmidhuber 2006)		
	Committee selection strategy (Togelius et al. 2014)	Clustering (Yannakakis et al. 2013)	Active learning (Togelius et al. 2014)
	Classification and regression (Yannakakis et al. 2013)		
Sensory data	Neuroevolution (Pedersen et al. 2009)		Cognitive appraisal theory (Frome 2007)
			Usability theory (Isbister and Schaffer 2008)
	Neural network and clustering (Charles and Black 2004)		Belief-desire intention (Ortega et al. 2013)
			Facial action coding system (Ekman and Friesen 1978)
In-game data	Neural network (Charles and Black 2004; Pedersen et al. 2009)	Clustering (Drachen et al. 2009)	
	Supervised learning with labels (Togelius et al. 2014)		
	Multilayer perceptron (Togelius et al. 2006)		
	Sequential minimal optimization (Spronck and Teuling 2010)		



Game Player Modeling, Fig. 1 Inputtypes, modeling approaches, analysis, and applications of game player modeling

Kivikangas et al. 2011; Nogueira et al. 2013a, b). Game player modeling is also experimented in some commercial games (e.g., Tomb Raider, Civilization IV, and Left 4 Dead), but there are still some problems of generalization (Drachen et al. 2009; Spronck and Teuling 2010; Ambinder 2011). Even though player modeling can be generalized, there is still a gap between the player's characteristics within a game and the real world which needs to be bridged in the future research (Holmgard et al. 2014).

Cross-References

▶ Constructing Game Agents Through Simulated Evolution

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Game Production Effort

► Domain-Specific Choices Affecting Design Effort in Gamification

Game Project

► Game Thinking X Game Design Thinking

Game Prosumption

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Synonyms

Playbor; Gamers; Multiplayers; Producers; Consumers; Co-creation; Network economy

Definitions

Game prosumption refers to the process of both production and consumption of computer games rather than focusing on either one (production) or the other (consumption).

Introduction

Concept of prosumption was first introduced by Toffler (1980) as part of his futuristic outlook to the post-industrial age. Kotler (1986) found the idea of involving individuals in the production of the goods and services they consume rather provocative. Yet, it took a while for consumers not to be considered as passive responders but active creative actors contributing to the value creating process (Xie et al. 2008).

Key Principles and Concepts

In its contemporary use, prosumption implies that consumer participate in the production of the goods that they consume (Ritzer and Jurgenson 2010). Accordingly, presumption involves more than just a single act. It is an integration of participatory physical, mental, and/or social actions in the process of creating desired products. These roles of consumer and producer blended and blurred even more with the introduction of digital media (Pathak-Shelat 2014).

Digital Prosumption

In the digital and online world, prosumption actions are not necessarily solely physical, but may also be virtual. Digital technologies provided more opportunity and visibility to consumer's input in various design, manufacturing, and distribution dimensions of prosumption (Rayna and Striukova 2016). The emerging network economy enabled further prosumption possibilities for market participants and consumers alike (Grün et al. 2011). Individuals, on the other hand, not always wanted to engage in co-creation by contributing their valuable time. Indeed, some argued that vast majority were happy to be only passive consumers at the lack of incentives (Haque 2010). However, games provided the much-needed incentive.

Contemporary Computer Game Prosumption

Most computer gaming experience involves the gamer's engagement in the production of an episode of game play, which is then simultaneously consumed (Harwood 2011). Gaming itself is a prosumption activity. Furthermore, gamers consuming multi-player e-games not only buy and play but also observe other players actions. This collective action produced is then called a virtual game. The integrated experience of online play containing labor during virtual gaming is also referred as *playbor* (Kücklich 2005; Ritzer 2014; Schott 2010).

Examples

There are some players who choose to dedicate an extra effort to modify the games they play, such as the creators of Counter-Strike, Minh Le, and Jess Cliffe (Kücklich 2005). With the advent of highly profitable sandbox games, more players are introduced to prosumption of their own story as they interact with the game world, decide for themselves what they want to play.

Cross-References

- Area of Interest Management in Massively Multiplayer Online Games
- Immersive Technologies for Medical Education
- Online Players: Engagement, Immersion, and Absorption Across Secondary Worlds
- RTS AI Problems and Techniques
- Videogame Engagement: Psychological Frameworks

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Game State Validation

► Secure Gaming: Cheat-Resistant Protocols and Game History Validation

Game Strategies

► Strategies for Design and Development of Serious Games: Indian Perspective

Game Studies

► Cross-cultural Game Studies

Game Thinking X Game Design Thinking

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Synonyms

Game development; Game project; Gamification

Definitions

Game thinking (or gamification) is related to game-oriented thinking, in processes that are not games, aiming to reach a specific objective and using engagement mechanisms.

Game design thinking is focused on the design and development of games based on design thinking methodology.

Introduction

The concepts of game thinking (or gamification) and game design thinking are commonly mixed, although both have different proposals and

Game Thinking X Game Design Thinking, Fig. 1 Gamification or game thinking process (Reproduced from Manrique 2013)

applications (Deterding et al. 2011; Castro 2013; Jewell 2016; Sailer et al. 2017). Marczewski (2014) performed an analysis involving the main differences between game design and game thinking and points out that, while the game design is related to something that entertains people in a fun way, the game thinking proposal is to do something in order to achieve a specific goal.

The term game thinking relates to the use of game elements in contexts that do not necessarily consist of games and/or digital media resources (Currier 2008; Alves 2008). Paffrath and Cassol (2014) argue that game thinking is related to understand different aspects of human psychology, such as the mechanisms of personal motivation and the concept of fun.

Game design, on the other hand, explores mechanics and gameplay, among other things, to make the game enjoyable (Silva and Bittencourt 2016). In this sense, game design thinking is a methodology focused on the design and development of games based on adapted concepts of design thinking and that can be developed in a significant way to the process of design and game development (Gestwicki and McNely 2012).

Considering these aspects, this article discusses the main differences between game thinking and game design thinking and presents a methodology proposal for game design based on design thinking and agile and lean project management concepts. We also discuss the results obtained from the application of such methodology in classrooms of undergraduate courses related to the game design.

The text is organized as follows: In addition to this introductory section, section "Game Thinking and Game Design Thinking Methodologies" addresses the main issues related to game thinking and game design thinking. section "Game Design Thinking" presents the game design methodology proposal, and, finally, section "Conclusion" presents the final considerations.

Game Thinking and Game Design Thinking Methodologies

Both game thinking and game design thinking have their own goals. The game thinking focuses on pushing the participant toward their business goal, while the game design thinking explores mechanics and gameplay, to make the game enjoyable, employing design thinking as a game development methodology.

For game thinking, there are different application proposals in the literature (Liu et al. 2011; Werbach and Hunter 2012; Guin et al. 2012; Landers and Landers 2014). These proposals apply some common steps to the game thinking methodology: definition of challenge and goals, identification of target behaviors, players' understanding, and specification of the fun activity. Figure 1, proposed by Manrique (2013), summarizes these steps.

The first step is the definition of the challenge and goals that will drive the game thinking process. In addition, it is necessary to understand the profile of the players in order to plan activities that motivate them. In this context, the definition of fun activities is the core of the gamification process.

On the other hand, in the game design process, formalisms and methodologies are needed in order to optimize, streamline, and professionalize the game development (Hunicke et al. 2004; Bem et al. 2014; Kristiansen and Rasmussen 2014; Jewell 2016). It is noted that the game design still requires specific methodologies, capable of giving developers the understanding of the game development process in a complete way.

Gestwicki and McNely (2012) argue that the adoption of design thinking as a methodology for the game development is adequate because it provides immersive process based on research, bringing academic objectives closer to business environments. In addition to immersion, the generation of ideas, the possibilities prototyping and the selection of solutions are characteristics of design thinking that can be adapted to the game design. According to Vianna et al. (2012), design thinking is originated from the need to seek new paths to innovation from the human-centered approach, where multidisciplinary, collaboration and the tangibilization of thoughts and processes lead to innovative solutions.

However, while the game thinking area presents methodologies that have a common and well-founded basis, the area of game development lacks proven methodologies, which help game designer to think about the creation process of the game. In this sense, the next section presents a proposal of a game design thinking methodology.

Game Design Thinking

The game design is characterized by the constant need for innovation and reinvention in order to meet new audiences, new static, new experiences, and new technologies. The professional who works in the game design must be able to integrate different aspects necessary to the proposal of a game, which has a multidisciplinary nature. In this sense, the area of design thinking has added quality to the game design, since it is an active and user-centered methodology in addition to preaching the culture of innovation. The latter can be considered as the intersection between three common constraints involving design thinking: desirability, feasibility, and feasibility.

This section presents an evolution of our previous methodology for game design based on design thinking (Silva and Bittencourt 2016). The original proposal was adapted in order to following the iterative cycle of refining designs and getting user feedback as proposed by Wagner and Piccoli (2007).

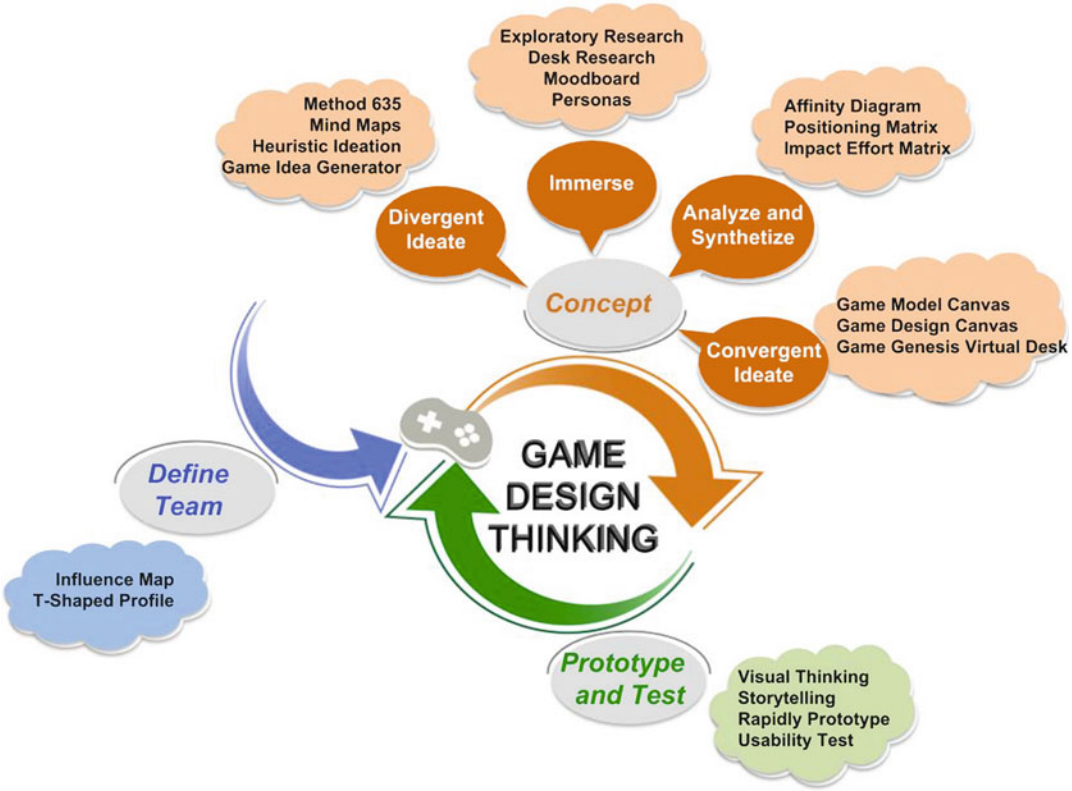
The Methodology

This methodology is divided into four main stages: team definition, conception, prototyping, and validation. As can be seen in the Fig. 2, after the team definition starts, an iterative cycle of conception, prototyping, and tests is realized.

The team definition is a fundamental step to reach the objectives of the game design, due to its interdisciplinary character related to the different stages of conception and prototyping. Team members should interact with each other, identifying opportunities and developing creative and innovative solutions for the game development process. Thus, the team must know each other, focusing on the personality of the members as well as their professional aptitude. For this first stage, two strategies are proposed: influence map and T-shaped profile (Glushko 2008).

In addition to the game objectives, the game conception depends on four basic premises: inspiration, creativity, innovation, and identification of tendencies. Such premises must be present in all phases of conception: divergent ideation, immersion, analysis and synthesis, and convergent ideation. It is noted, therefore, that the conception begins and ends based on the creative process and its two types of thinking: divergent and convergent.

Divergent ideation seeks to create options, from a significant quantity and diversity of ideas, in order to promote different possibilities of game design for the immersion phase. Thus, different brainstorming techniques can be applied, as the method 635 (Rohrbach 1969), the mental map (Buzan and Buzan 2006), the heuristic ideation technique (Gray et al. 2010), and game idea generator tool (Riftpoint Entertainment 2017).



Game Thinking X Game Design Thinking, Fig. 2 Game design thinking (Adapted from Silva and Bittencourt 2016)

After the divergent ideation, the immersion stage identifies the needs and opportunities that will guide the generation of solutions in the next phase of the project. For the game development, four techniques are suggested at this stage: exploratory and desk researches, moodboard, and personas (Vianna et al. 2012; Gray et al. 2010). These tools help in the understanding of the game scenario, through information about the theme of the project from diverse sources (websites, books, journals, blogs, papers among others), and the identification of market niches, with little exploration and potential for expansion.

In the analysis and synthesis step, definitions related to the game must be made. In addition to the data gathered in the exploratory research and the moodboard panel, cards created in the desk search can be arranged in an affinity diagram to identify similarities and patterns between them. Positioning and impact matrices also can be applied at this stage to the definition of criteria such as time, complexity, innovation, costs, team members' abilities, and motivation among others.

The convergent ideation closes the game conception phase and is characterized by making choices based on existing alternatives related to the game. In this step, the ideas generated in the previous steps are critically analyzed and judged so as to select them based on previously defined criteria, expanding the original ideas. In this stage, it is proposed to use two main tools for the convergent ideation of the game: game model canvas (Jimenéz 2013) and game design canvas (Sousa 2014). Another tool that can help the generation of new ideas is the game genesis virtual deck (Gehling 2016). These tools allow the analysis of the game in a systemic, integrated and fast

way, providing insights on how the team should act in order to compose the main idea. It thus helps game developers build, differentiate, and innovate processes, improving their business model to win over the target audience and gain profits.

During prototype and tests, four major actions should be considered: rapidly prototype, publicize/publish the game for feedback and evaluation, feedback analyze, and make improvements if necessary. However, before the prototyping, it is important to align the development process with the team members, and two resources can be used for that: visual thinking (Ware 2008) and storytelling (Rouse 2000). Once the process is clear to team members, the game's implementation begins by choosing technologies that are easily integrated and make it possible to obtain the final designed product.

Finally, the game developed must be published in order to get feedbacks and evaluation of player users. For this, remote and face-to-face usability tests supported by the Likert scale (Likert 1932) are recommended. According to Nielsen (1994), usability comprises five dimensions: learning, memorization, errors, efficiency, and satisfaction/acceptance. Based on the results of testing, the most recent iteration of a game design, changes, and refinements are made, and a new cycle starts.

Case Studies and Results

This methodology was applied in 15 undergraduate courses of different institutions of higher education since 2014. Through an empirical analysis, it can be observed that the methodology of game design thinking allowed groups of students to work in a "free" , focusing on high level concepts.

Thus, as the flow of the methodology progressed, the students had more creative ideas, connecting points not so obvious from the initial premises. The phase of divergent ideation allows the teams an enriching brainstorming, "opening their minds" for the generation of game concepts. In the immersion stage, there is an evolution in the students' original ideas, while the analysis, synthesis, and convergent ideation stages allow the definition of the game concept in an agile and efficient way, summarizing the game design in panels which facilitate the identification of trends, creativity, inspiration, and innovation among team members.

Some groups that started the game design thinking process with a pre-defined concept of their game felt motivated to rethink this. During the prototype stage, the adoption of visual thinking and/or narrative allowed a complete visualization of the flow and mechanics of the game. Later, the construction of the game based on rapid prototype promoted the initial understanding about mechanics and interaction proposed before the development of the complete prototype.

In some cases, the game design thinking results motivated groups to abandon the idea of digital gaming and invest in a board game, given that the board proposal exceeded the digital proposal in terms of gameplay.

Conclusions

This article discusses the main differences between the terms game thinking (gamification) and game design thinking. While for gamification there are a significant number of proposed and proven methodologies, for game design there are few methodologies that really point to design and development stages in an agile and lean way, stimulating inspiration, creativity, innovation, and identification of trends.

Then, a methodology based on design thinking for the game design is presented and discussed in practice, with the report and analysis of case studies results. The results obtained from case studies show the generation of more interesting games when compared to games developed without the use of a methodology that stimulates creativity and innovation such as design thinking methodology.

This study intends to contribute to the area of digital game design and development, either professionally or in activities that involve the learning process.

Cross-References

- Challenge-Based Learning in a Serious Global Game
- Gamification
- Game Development Leadership Tips
- Gamification and Serious Games

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Game Usability

► Player Experience, Design and Research

Game Venues

► Game Venues and Platforms

Game Venues and Platforms

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Synonyms

Game platforms; Game venues

Definitions

Game venue = a physical place where one or more persons can play a video game.

Game platform = a device suitable for playing video games, e.g., a console, a smartphone, or a PC.

What venues do we think of when we think about playing games? The dining room table with a board game, the computer desk in our office, or the living room in front of the TV? The location of the "venue" of a game can be a direct result of how successful the game can become. If we were to design a game, the decision of what platform – console, PC, tabletop, mobile, or tablet – is an important decision to make. For centuries, humankind has revolved around many different aspects when it comes to the social aspects of entertainment.

Studying history we can see how our choices for entertainment and comfort have changed. Just look at the evolution of the TV going from something that we see in stores and restaurants for public entertainment to be a staple inside of the poorest of homes in America. The same can be said about games and the platforms they are running on. In the 1980s, a game console was rarely found in a household, but today, more than 89 million American households own at least one type of game console or a PC. Over 40% of them have multiple types of gaming consoles or platforms (Statista 2018).

The type of games can affect the kind of venues. For a game that tells a grand story with videos and cinematic scenes, a console connected to a big screen in the living room is a good choice. A game that brings people together to spend quality time playing would call for a tabletop game, such as cards or board games. For a massively multiplayer game connecting hundreds of people around the world, a PC would be the best platform.

The main issue with consoles is that it can be limiting and expansive at the same time. Currently, there are three companies who are at constant battle with one another to dominate the console war: Microsoft with their Xbox One X the console which has the fastest graphics and processing speed, Sony with the PlayStation 4 Pro that is a serious contender to Microsoft with their console exclusive games, and Nintendo Switch which has the ability to seamlessly swap from console on the big screen to mobile handheld console in an instant without compromising the current gaming activity.

It is ideal for a game to run on all platforms. However, if, say Sony PlayStation decides to make a game its console exclusive, it would take away

the three-company bliss and cut it down to one, literally reducing the game market size by 66%.

Another consideration is input devices for game platforms. Consoles offer a more limited control through a controller whereas a PC keyboard allows a wider range of controls. The Xbox and the PlayStation controllers only has 12 individual buttons with 2 joysticks, which provide a range of combinations but are less than an average PC with a keyboard of 62 buttons plus a mouse (Rigg 2018). Depending on basic versus gaming equipment, the mouse itself may have extra buttons on it, making it the best contender for button combos and linking actions to buttons. The PlayStation Controller does have one advantage against its competitors, a large Touchpad at the top of the controller. It is designed to allow the player to swipe and click on information very much like a laptop touch pad. So far it seems to only be useful for menu navigation, but with the redesign Sony was planning on a future with new innovative games which will include the Touchpad into their game. Nintendo Switch comes with two controllers, Joy-Con L and Joy-Con R, each of which contains an accelerometer and gyroscope for motion control support. All three companies have designed motion control systems before, Microsoft with the Kinect from Xbox 360 and Xbox One, Sony with the Playstation Move for the Playstation 4, and Nintendo who has been doing it the longest with the Wii, Wii-U, and now finally the Switch. The Switch Joy-Con's are possibly the most accurate out of any companies attempt at motion control. The actions with the controller are spot-on: if you overexaggerate your actions, the results appear on screen as overreacted. It is a finely tuned gyroscope inside of the controller. Not to mention that 9/10 games produced for the Nintendo Switch make use of this motion control, unlike many predecessors which only had a few games made to use the motion control.

There are also arguments between gamers about which one offers a better reaction time: the joystick on a controller versus a PC's mouse. Most gamers agree that the PC's mouse outperforms the console's controllers. In addition, most computers that are built for gaming have a high-quality graphics card and processing power to be able to play games with better graphics quality and reaction time. Nevertheless, Microsoft is closing the gap on PCs by adding keyboard and mouse support on Xbox One in 2018.

While mobile and tablet game platforms are less powerful than consoles and PCs, they have a built-in touchscreen and other features that make them unique. The large amount of people that own a smartphone means that mobile games have a large potential reach. The ability to play games anywhere enables the creation of games that integrate GPS technology. Another application that can be used by game developers is the multiple cameras smartphones possess to run augmented reality, where graphics generated by software is overlaid from pictures from the camera. Games such as *Pokémon Go* has used all of these technologies to allow players to travel to a place in real life and then catch a Pokémon using the touchscreen and augmented reality. For games that would require a proper controller, games can utilize the smartphone's bluetooth technology to allow a user to buy a third-party controller, pair it with the smartphone, and then affix the phone to the top or middle of the controller. Likewise, iOS and Android operating systems allow their users to project their screen onto another device for a better viewing experience.

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Game with a Purpose

▶ Hypermedia Narrative as a Tool for Serious Games

Game Writer's Dilemma: Context vs. Story

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Synonyms

Context; Game writing; Narrative; Narrative design; Storytelling

Definitions

Narrative is a fictional, cohesive universe made up a mythology of characters and settings bolstered by a story (but often a series of stories), theme, and tone. Story depicts a character's journey that, through a series of escalating challenges and accomplishments, results in that character's self-discovery. It is part of a narrative, but, by itself, is not. Context is descriptive, light information that provides a player with justification as to why he/she is about to take on a certain task or pursue a certain goal. It is also filler or casual stimuli, like ambient dialogue, that provide authenticity to a world.

Introduction

There is an industry-wide confusion over the role of narrative in games. Often times, it is confused with context. This entry will define "narrative," "story," and "context" and provide how their applications in the game experience are distinct from one another.

Overview

A writer does not have an enviable role in video games. Sure, game writing beats writing copy for a hardware catalogue. And it is more fun than writing dry text for, say, an academic publication. (Irony acknowledged.) But in the world of video games, writing is often a misunderstood craft and, as such, is often shunted to the side until the very last minute of a game's development.

There are many reasons for this, including (1) people think, because they have the ability to write sentences, that they have the ability to write a narrative; (2) writing does not involve lines of code, thus words are easier to adjust at the last minute to fit features that are perceived to be cool at the time; and (3) gameplay is king and thus story must be subservient to it.

The last point is unassailable. Games are a gameplay-driven medium. If one wants to work in this field as a writer, the first thing he/she must understand is that narrative will need to serve gameplay, not vice versa.

But the other two points are unnecessary yet frequent obstacles that often hinder a writer. Fake understanding of the craft is common and dismisses its burden. A nonwriter's attitude is simply, "I write emails and texts all the time. It's so easy. Anyone can write." Obviously, this facile comment ignores thousands of years of story innovation including compelling characters, plot, structure, and theme. More importantly: crafting words to communicate these requirements of storytelling is not the same as crafting an email. (If so, why not then abnegate the works of Homer and Shakespeare?) But what is dangerous about this attitude is that it lowers quality expectations, encourages amateurs to assume the role of writer when companies are crunched for budget, and does not allow for producers to allocate enough time or personnel for story development.

Writing story is also viewed as a lesser craft than writing lines of code. Accordingly, writers are often pushed to make dangerous compromises on story in order to avoid upending a feature that is hard-coded into the game. It is foolish to say that storytelling is harder than programming. Because it is not. But it is also foolish to say that

storytelling is easily flexible, so moldable to whim. Because it is not. Yet, it is often "strong-armed" by whim to change ad infinitum. Such arbitrary demands are myopic and cavalier, and often lead to the compromise of quality. Story beats will be abbreviated and then combined into a later one, at which time a player will be deluged with too much information. Even worse, casually thought-out rescoping can lead to serious coherence issues.

All of these pitfalls are a result of one common problem: a profound misunderstanding of what narrative is.

This entry will focus on a particular type of misunderstanding (yes, there are many) that does not necessarily over-tax the writer, but nor does it empower him/her to maximize the craft to its fullest capacity. It is the misunderstanding of the term "context." So prevalent is its confusion with narrative that it is the intention of this entry to correct the record once and for all.

What Is Narrative and How Does It Get Misused

In the recent history of game development, narrative has become a "nice-to-have" feature in an industry where gameplay reigns supreme. Of course, there are a multitude of games that are narrative-centric or, at least, that push story as a major feature. (Telltale Games, for instance.)

But narrative still remains, for a significant majority of games, an after-thought to game design due to popular expectations from players. Disruption of the gameplay experience is a high crime, and narrative is often seen that way. Even if the vehicles that deliver narrative are interactive (like cinematics) and offer direct incentives that enhance gameplay (boosts, for example), players often do not look forward to these mini departures. Writers do not welcome this approach either. Narrative gets diluted when it offers incentives to a player just to validate its existence.

For the most part, games are not a narrative-driven medium.

Nonetheless, this does not stop game studios from wanting to include narrative in their games. As they should. But "narrative" is not universally understood. Each game studio, in fact, might have their own definition. To be clear:

Narrative is not text on screen.
Narrative is not writing 27 different ways of saying, "Take cover!"
Narrative is not mission descriptions.
Narrative is not tutorials.

What narrative is, instead, is a fictional universe made up a mythology of characters and settings bolstered by a story (but often a series of stories), theme, and tone.

It does not stop there. Narrative is also responsible for the granular details that buttress these pillars and provide necessary information, authenticity, and orientation for a player's journey.

It is the overemphasis on the granular details, however, which the majority of game companies incorrectly define narrative to be: the minutiae.

So yes, narrative does involve: text on screen; 27 different ways of saying, "Take cover"; mission descriptions; and tutorials. But without a central, cohesive fictional universe, these discrete parts do not add up to narrative.

Individually, they are, instead, context.

What Is Context?

Context is descriptive information that provides a player with justification as to why he/she is about to take on a certain task or pursue a certain goal. It is also filler or casual stimuli, like ambient dialogue, that provide authenticity to a world. (Think of combat chatter in *Call of Duty*.) Context is light information and does not provide enough connective tissue from one moment to the next to be defined as narrative.

Context is necessary in the sense that, without it, players will not understand why they are about to embark upon a certain part of a journey or what the immediate goal will be.

Context also has an important role in reinforcing the fictional universe, be it through communicating the personalities of characters of the game, backstory of the world, or game rules. Tone is also a critical driver of context and vice

versa. For instance, Rolf and Jenny land their ship on a desolate planet, hoping to find a lost ship of fellow explorers. Rolf and Jenny are a married couple and are ambitious scientists with a penchant for puns. When they come across a volcano on the verge of eruption, on-screen text tells them they must cross the volcano to reach the other side of the mountain, where a light beacon assures that they will reunite with one of the lost crew members. Here we have an excellent opportunity to infuse the on-screen text with some of Jenny and Rolf's humor. "They've studied the topology of this planet before. Therefore, the volcano's volatility is no surprise. The only test here is their *lava* for one another."

This type of context informs a player of the following (1): Rolf and Jenny have an extensive knowledge of the planet; (2) Rolf and Jenny knew of the planet's volcanic activity prior to landing; and (3) Rolf and Jenny have a terrible sense of humor.

As long as it reinforces what this world is about and remains consistent, tone can go a long way in adding more flavor to context and, in turn, reinforcing the narrative even if through secondary impact.

What Is Story and How Does It Differ from Narrative?

Story depicts a character's journey that, through a series of escalating challenges and accomplishments, results in that character's self-discovery. Upon that self-discovery (also known as anagnorisis from Aristotle's *Poetics*), a character will face a big decision: Will they change for the better? Will they continue on their path but with larger challenges ahead? Will they do something selfless for the betterment of those around them?

Story is a progression of a hero. Everything he or she encounters along the way should enhance the stakes of that progression and provide more insight into the hero's psyche and past.

Story is a critical part (often times, the majority) of a game's narrative. But story, by itself, is not narrative. Narrative is the bible that is comprised of a series of related stories, characters, and environments. Narrative is the fictional universe, the elements inside, and the connective tissue that binds those elements together. Where story needs a protagonist, narrative needs a world or universe of which that protagonist is a part. Where story moves forward through plot, narrative moves forward through mythology and world building. Where story is the single journey of a single hero, narrative is potentially an endless series of journeys and incorporates many heroes.

Why Is Not Context Story?

The light information that context provides is critical to orienting a player on their path forward. But it is not an ideal vehicle for story as it can hamper a player's momentum. Stopping to read long tomes of story will engender resentment from most players. And bite-sized, frequent appearances of on-screen text are met with equal disapproval. These instances happen more frequently than one can imagine.

Context should never be expected to do the heavy lifting for story. A few reasons why (1) a mission could be added after the development of the story has been "baked" and is therefore inelegantly shoe-horned into the core progression; (2) one-off activities (e.g., sports drills, tutorials, missions, live raids, etc.) may not be thematically or structurally related, and therefore imposing a faint connection that ties them together will, most likely, dilute or neuter story; (3) the game is comprised of an endless stream of missions or grinding activities in which ongoing story would fail in quality or logic to serve as an effective complement.

However, context would still be appropriate to give a player an understanding of basic stakes and consistency to the world that was already set up in the narrative (assuming a narrative was established in the first place).

But due to its nature, context does not move the story forward. It provides ancillary, and sometimes inconsequential, information that keeps a player aware of stakes. But there is nothing in that information that contributes anything emotional or meaningful to the hero's psychological journey, the main force behind story.

Context is narrative in its lowest, most unambitious form. It is one step above stimulus.

Cause for Confusion

The most common use of context in games is through on-screen text and informational voice-over, which are very attractive for game developers as they provide low cost solutions for tutorialization and player orientation.

But to label words on screen or informational voice-over, without having any other elements of narrative, *as narrative* is to diminish the craft of writing. This oversight or lack of understanding by video game professionals is neither malicious nor negligent. One can attribute the prevalence of the misuse of these terms to the rise of social media.

Due to the increased volume and accessibility of content creation tools on mobile, terms such as "story" and "narrative" have become less clear now that social media companies have co-opted those terms to mislabel new digital products. *Snapchat My Story,* for instance, is often a collection of disconnected videos that do not build to a cohesive message. *Instagram Story* is no different in result (other than it features photos only). It is the culture – not the game developer – that has obfuscated the meaning of story.

Conclusion

Narrative, story, and context are often used synonymously in game development; however, as described above, they are not the same. As media changes, so does the craft of writing. Keeping up with how stories are told year after year remains a challenge for writers. So, too, does the ability to communicate the distinctions between narrative, story, and context.

Video game story professionals need to tackle that task effectively. Doing so will result in realistic expectations from engineers, designers, and producers, and will empower writers to advocate for narrative in ways that it deserves.

It is the hope of this author that nonwriting professionals in game development will soon understand that pushing narrative to its artistic maximum (including its original intention) will result in higher quality games, no matter the genre.

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Game Writing

▶ Game Writer's Dilemma: Context vs. Story
▶ Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation

Game-Based Approach

▶ Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay

Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay

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Synonyms

Game-based approach; Games for health; Gamification; Health games; Serious games

Definition

Game-based intervention in public health: *exploiting the engaging factor of gameplay* is the application of game science, techniques, and technologies for supporting public health

interventions, specifically focusing on serious games and gamification approaches. Serious games refer to digital game technologies that serve a purpose other than pure entertainment, and gamification is a technique that exploits game concepts and mechanics in non-game contexts in order to motivate engagement and sustain participation in serious activities.

Introduction

The increase of health impediments due to unhealthy lifestyle has put a lot of pressure on public health spending. Even though public health programs are important in raising awareness toward lowering the prevalence of physical and psychological health complications, the general public should be made accountable for their own health and well-being. The approaches by which awareness is raised, attitudes and behaviors are transformed, and positive habits are nurtured should be improved to be more effective, which could potentially ease pressure on public health services in the long run.

The level of receptiveness to public health awareness programs is highly subjective to whether positive engagement, persistent involvement, and discourse can be fostered. There is a growing interest in improving and sustaining engagement with such programs across the healthcare sector using technologies, such as digital games. Games such as America's Army, for instance, are able to reach a large number of players and engage them for long periods of time, which has encouraged gaming to be used to achieve serious outcomes, such as cognitive gain, awareness raising, and change of attitude and behavior.

Games as positive technology capitalize on its engaging and fun characteristics toward fostering positive emotions, nurturing positive habits, encouraging positive attitude and behavior, and promoting optimal human functioning. Game approaches can be used as an enabling tool and/or concept to promote qualities that could enable individuals and communities to strive for and build the best in life. McGonigal (2011) and others have continued this approach, leading games for change projects that raise awareness and support good causes or try to change behavior for social purposes. Self-regulation and health coaching, for instance, have a big potential to empower individuals, and combined with mobile and social platforms, game-based approaches could facilitate community building and peer support system around healthy lifestyles in a more pervasive and active way.

The need for efficient and effective education of healthcare professionals has also seen game-based approaches employed in a diverse range of forms to address training needs, while in a clinical setting, games have been used to improve therapeutic outcomes for patients. Fundamental to the success of game-based intervention across these areas is the ability of designers to realize the power of interactive and immersive environments to engage and immerse the users while conveying learning outcomes in a demonstrably effective fashion. Research, therefore, must play a key role in identifying the strengths, weaknesses, and best practices in the use of game technologies and techniques in the healthcare sector, providing decision-makers with the evidence they need to consider their value as a solution.

With these perspectives, this chapter provides an overview of the implications of using game concepts and technologies for supporting health interventions and discusses key development trends and challenges. The next two sections, respectively, introduce serious games and gamification initiatives, discuss their contributions to and potential in health interventions, and conclude with lesson learned and trends in the domain. The conclusion section summarizes and highlights key takeaways from this chapter.

Serious Games and Health

By definition, serious games refer to applications developed using computer game technologies that serve purposes other than pure entertainment. The term has been used to describe a variety of game types, particularly those associated with

Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay,
Fig. 1 Screenshot from "Privates" game (www.sizefivegames.com)

e-learning, military simulation, and medical training. Serious games capitalize on their ability to reach target audiences who are already engaging with interactive, rich graphic games recreationally, allowing them to convey instructional outcomes to audiences resistant to more formal methods.

The application of games within the health sector ranges from tackling sexual and mental health to promoting healthy living and raising awareness on pharmaceutical processes. The Privates game (Fig. 1), for instance, has been commissioned by UK's Channel 4 TV Company to engage and educate young people on sexual health issues. Other entities such as the Parliamentary Education Group, DEFRA, and the US government (who held a competition around games for health) are also increasingly commissioning games for learning purposes (Ulicsac 2010). Physical and mental rehabilitation has been promoted via the PlayMancer game, which was awarded the Best European Health Serious Game in 2011 at the Fun & Serious Games Festival in Spain. Most recently, the EU-funded PEGASO project exploits game technologies to support an ecosystem of beneficiaries in addressing challenges related to obesity, a worldwide public health problem (Panese et al. 2014). Inspired by the success of FarmVille, a pharmaceutical brand Boehringer Ingelheim releases their own game – Syrum – aimed at demonstrating the brand's continuous commitment in research and innovation and to educate the public on their product development process.

Recognizing the increasing popularity of digital games in health applications, there is a need for empirical studies to be carried out that can serve as benchmarks for establishing scientific validity for the efficacy of such an approach. This is a critical trajectory for the application of games within the healthcare contexts as to encourage uptake within formal deployment; existing initiatives should move "away from the evangelistic early stage work to the practicalities of implementing and testing game technologies in real contexts of use" (Arnab et al. 2012). For example, several important studies have been undertaken that have shown the efficacy of game-based approaches over traditional approaches (e.g., Hainey et al. 2011; Kato et al. 2008; Knight et al. 2010; Marchiori et al 2012; Brown et al. 2012; Arnab et al. 2013). The first controlled trials for game-based intervention (Kato et al. 2008) showed how game-based approaches in the Re-Mission game (Fig. 2) fostered medication adherence in children with cancer.

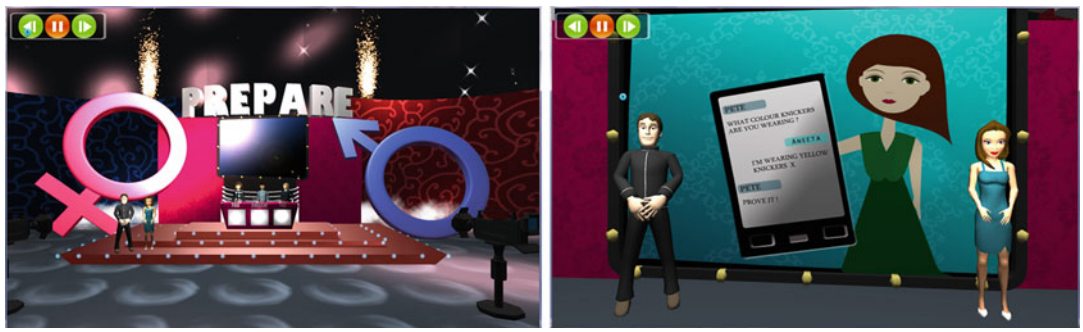
Other examples include a game-based intervention to support the delivery of relationships and sex education (RSE) program (Fig. 3), a game called PR:EPARe (Positive Relationships: Eliminating Coercion and Pressure in Adolescent Relationships) developed by the Serious Games Institute and the Studies in Adolescent Sexual Health (SASH) research group at Coventry University, UK (Brown et al. 2012; Arnab et al. 2013). A cluster-randomized controlled trial in local schools ($n = 505$) demonstrates positive outcomes in favor of the game-based

approach when compared to existing methods based on surveys of self-reported measures of psychosocial preparedness for avoiding coercion or coercive behavior. The *Serious Games for Healthcare* book (Arnab et al. 2012) highlights existing research and development trends, methodologies, and experimental work in the use of game technologies to address health-related topics, which aimed at progressing the understanding of serious games, the methodological rigor, and the implications. This volume explores the issues including ethics, modern game engines, design considerations, and research methodologies underpinning the use, evaluation, and validation of games applications.

For a game to be considered "serious," its efficacy should be proven rather than simply intended, and games should not be afforded exemptions from the rigor applied to assessment of other approaches to education and training across the sector. Only then can relevant decision-makers be provided with the evidence needed to make informed selections of game-based approaches as ideal solutions to specific intervention, learning, or training needs.

The study on the long-term behavioral impact is however longitudinal. Games' ability to reach and engage a large number of players for long periods of time provides an opportunity for vital user data to be recorded, monitored, and analyzed continuously. The challenge is how to best collect, record, and analyze the potential wealth of data and utilize the analysis to provide appropriate feedback and support to the individuals, which could potentially promote self-management and health coaching.

Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay, Fig. 2 The Re-Mission game (Kato et al. 2008)



Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay, Fig. 3 Screenshots of the PR:EPARe game (Arnab et al. 2013)

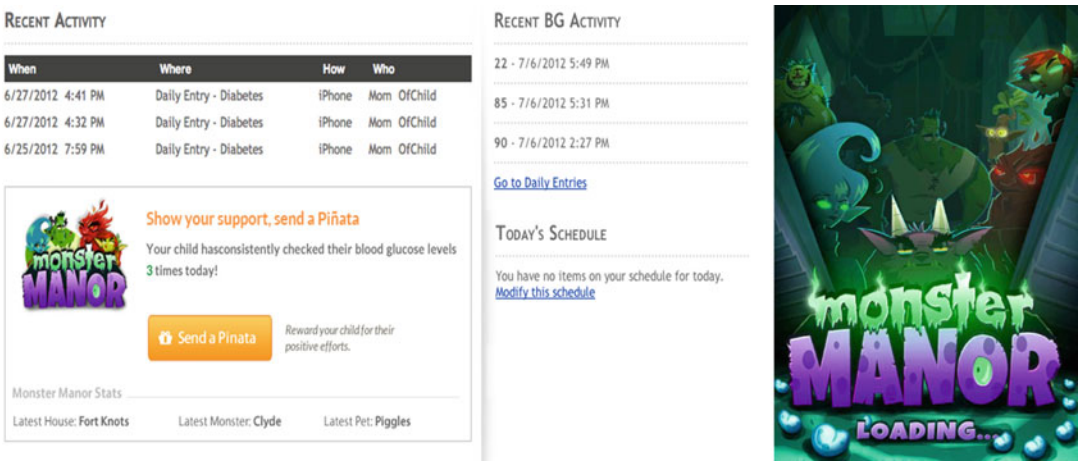
Gamification and Health

The need for a more long-term regulation of healthy behavior signals a move toward greater gamification, commonly defined as the use of game design elements in non-game contexts (Deterding et al. 2011). It will take the essence of what it is that makes games so appealing, decode the mechanics that makes them work, and then apply these mechanics in activities that activate psychological motivators, which in turn drive desired behaviors. A strong body of research work has already been generated and the number of new publications on gamification is growing daily, as underlined in a recent study (Hamari et al. 2014).

The pervasiveness of game (play) mechanics and dynamics employed in day-to-day activities to support serious outcomes is the current trend within the context of gamification. Gartner (2015) expects gamification to reach the "plateau of productivity" within 5–10 years; that is, mainstream adoption begins to take off and more rigid assessment criteria are evident. At this stage, the technology's general market applications and relevance are accepted (Gartner 2015). The biggest players exploiting this trend include the major health insurers such as Aetna, Cigna Health, UnitedHealth, and WellPoint. The main objective is to improve the health and health-related knowledge of their employees, which will subsequently help increase productivity and reduce health insurance premiums.

By tapping into our natural tendency to react positively to entertainment and the competitive nature of most gameplay, actionable steps to overcome personal challenges can be designed. This can potentially help initiate healthier activities in any number of areas: losing weight, sleeping more, making healthier food choices, improving fitness, monitoring health metrics, and medication compliance. Most of the activities will however require individuals to embrace delayed satisfaction, where the reward may be as elusive as the prevention of a chronic condition. With this perspective, gamification allows rewards and incentives to be used to sustain positive engagement. The fundamental fact of motivation is that we cannot be forced to change our behaviors. Behavioral change may be initiated by extrinsic sources of motivation or external factors that influence how we behave (Seifert et al. 2012).

Intrinsic motivation and positive habit may be nurtured through sustained engagement, where personal incentives and rewards for healthy behavior could be discovered. For example, the Monster Manor gamification program (Fig. 4) involves parents and clinicians in the "playful" and "incentivized" ecosystem aiming to motivate children with



Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay, Fig. 4 A support and rewarding system – a child plays Monster Manor, checks their blood glucose level, and receives a reward for positive efforts to be used within the game (www.ayogo.com)

Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay, Fig. 5 The Walk commissioned by the UK's Department of Health and National Health Services (NHS), exploiting the success of Zombies Run (www.thewalkgame.com)

type 1 diabetes to check their blood sugar regularly. The testing schedule was paired with a reward schedule in a virtual world of "pet monsters." Parents and clinicians can also intervene in this "Monster Manor" virtual economy to reward children for consistent checking. Other examples include an online and social community facilitated by the HealthSeeker program utilizing on competitions and recognition, where adults issue health challenges to each other through Facebook. Successfully completing shared "missions" will result in points that allow players to progress through the levels of the game. Analysis of the resulting data indicates that these peer-to-peer challenges are substantially more effective at encouraging change than simple software-originated challenges.

The pervasiveness of play spaces has seen gamification exploiting actual gameplay in both the physical and digital spaces. Games such as Zombies Run and The Walk (Fig. 5) exploit location-based mobile gaming to advocate running and walking, respectively. These initiatives intrinsically encourage "players" to run or walk as part of the mechanics for the location-based adventure game instead of explicitly campaigning about the benefits of running or walking as a fitness regime. Pervasive gamification, when coupled with wearable technologies, opens up exciting opportunities for individuals, who are not normally engaging with digital games to participate in positive playful activities anywhere and at anytime. Applications such as FitBit and Nike+ capitalize on mobile and wearable technologies and the common features of gamification (points, badges, and leaderboards).

Taking into account the behavioral challenges restricting the reach and effectiveness of health interventions, gamification could help to revolutionize the existing intervention for the general population into incentivized, future-looking, preventative, and personalized healthcare. Personalization provides individuals with a sense of control over their own healthcare. The benefit of gamification within the health sector is longitudinal and will require rigor in the evaluation of long-term efficacy. With the advancement in data tracking and analytics, qualitative assessment can be paired with data from the gamified activities to better understand the individuals and continuously provide personalized feedback within the engagement loop.

Conclusions

The use of game technologies and techniques in the form of serious games and gamification presents an opportunity for the engaging mechanics and dynamics of gameplay to be exploited in order to promote receptiveness to the serious message of public health campaigns. Longitudinal engagement with gamified platforms allows the facilitation of the recording and reasoning of large-scale health and well-being data. By better understanding knowledge, attitude, and behavior of the "players" and assessing their progress continuously, personalized and actionable feedback can be provided to nurture healthier habits. The academic labeling and debate by semantics and taxonomy quantize the differences between

gamification and serious games. However, the aims of any of these terms are that they are all trying to solve a problem and motivate using game-based thinking and techniques (Kapp 2012).

The generations who grew up playing electronic games increasingly represent and include both professionals and decision-makers in the healthcare sector, which makes increased receptiveness to this form of instruction becoming more apparent. If this receptiveness is coupled with the research required to validate and refine the use of game-based approaches across a wide range of applications, this may lead to exciting opportunities to address challenges existing interventions have so far failed to satisfactorily overcome. As the public health sector increasingly pressed to tackle chronic diseases and behaviors among the general population, the introduction and discussion put forward by this chapter, alongside the past and current projects in the area it highlights, suggest game-based interventions may form a critical part of a long-term strategy to address these challenges.

The diminishing boundaries between physical and digital spaces provide great opportunities for game-based approaches to be applied in everyday contexts. Game mechanics are becoming more pervasive as real and virtual interactions and events are merged within the context of gameplay. The application of gamification and pervasive gaming, such as The Walk and Zombies Run demonstrates the potential for gameplay to be a key catalyst for the nurturing of long-term healthy behavior. As the sophistication of mobile and wearable technologies is advancing, for instance, the potential for a more connected and seamless gameplay experience within a hybrid space will be possible.

The future trend in games and gamification will thus exploit such a hybrid space, which will see the crossings between pervasive gaming and gamification that will inject gameplay into their surroundings and community. The advancement of the Internet of Things (IoTs), mobile technology, and data analytics will allow everyday spaces to be transformed into a personalized playground enriched with contextual resources and activities. Self-reinforcement of personal healthcare will be more enhanced and engaging, relevant, and ubiquitous. Anytime, anywhere healthcare when gamified will introduce playfulness, competition and collaboration-playful healthy "regime," competition to drive self-improvement, and collaboration to foster a community of health-conscious citizens.

Research plays a key role in experimenting and providing evidence in the use of game technologies and concepts in the healthcare sector. The prospect of a gamified and pervasive health and well-being ecosystem can potentially affect the design and deployment of health strategy and policy in the future. Despite significant challenges for researchers in this domain in terms of the lack of standard methodologies or formulaic frameworks that guarantee success and efficacy, there are some empirical studies that can serve as benchmarks for establishing the scientific validity. There is thus a need to tap into best practices of such a multidisciplinary domain and infuse knowledge from relevant disciplines within the application domain toward developing an infused and transdisciplinary methodological framework that may act as a validated guide to inform the development process of a game-based approach.

Cross-References

- ▶ Cloud for Gaming
- ▶ Cognitive Psychology Applied to User Experience in Video Games
- ▶ Game Player Modeling
- ▶ Gamification in Crowdsourcing Applications
- ▶ Games and the Magic Circle
- ▶ Interaction with Mobile Augmented Reality Environments

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Game-Based Learning (GBL)

▶ Computer Games in Education
▶ Gamification and Serious Games
▶ Immersive Technologies for Medical Education
▶ Serious Online Games for Engaged Learning Through Flow
▶ Transformational Games

Gameplay Preference Categories

▶ Player Personas and Game Choice

Gamers

▶ Game Prosumption
▶ Online Players: Engagement, Immersion, and Absorption Across Secondary Worlds

Games

▶ Accessibility of Virtual Reality for Persons with Disabilities

Games and Active Aging

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Synonyms

Active learning; Active videogames; Cognitive games

Definition

Games are an important toll of active aging as they enable knowledge acquisition processes, attribution of meaning to information, and enhance quality of life and psychological wellbeing to the older people.

Introduction

The aging of the population is one of the main challenges facing contemporary societies. As a result of a shared social construction, there is a discursive "requalification" of aging, associating it with a terminological plurality that deconstructs the prevalence of negative stereotypes that associate old age with dependence, lack of autonomy, disease, institutionalization, and a disregard of their heterogeneity.

Social exclusion of the elderly is a consequence of globalization as well as the condition of second-class citizenship (Amaral and Daniel 2016) for those who do not have access to digital capital. Games can enhance quality of life of the elderly in three perspectives: cognitive, sensorial, and physical (Costa and Veloso 2015).

Active Aging

The requalification of aging has emerged with organizations such as the United Nations and the European Union that, since the 1980s and 1990s, have launched the concept of "Active Aging." New approaches and political solutions have leveraged this notion as a social representation for political and media discourses, seeking to combat the stereotypy that produces negative aging. The term "active aging" is the successor of concepts such as "healthy aging" or "successful aging." In 1997 the World Health Organization, inspired by the United Nations Principles for Older Persons, presented the concept of "active aging" as "the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age" (2002). Active aging is a concept that promotes the wellbeing of the elderly and includes the dimensions of health, participation, security, employment, independence, autonomy, and integration (Parra 2013).

Quality of life of older people may be affected within three macro-areas such as physical capacity, sensory capacity, and cognitive capacity (Parra 2013). Therefore, there is a need to create "innovative ways to re-invent strategies for sustainable active ageing and healthier lifestyles" (Costa and Veloso 2015).

Games and Active Aging

Games' approaches focused on healthy and positive aspects of individuals are transverse to the theoretical and empirical scientific contributions in this field. The individualization stands in the mainstream of political agendas to value the individual as a builder of his life course. The Declaration of Alma-Ata (1978) appeals to health for all and the need for health promotion models that avoid the traditional top-down logic (WHO 2002). It is the recognition of people's participation in promoting their citizenship as "the right and duty of the people to participate individually and collectively in the planning and delivery of health care" (WHO 2002). Giving digital competence to older people is a way to empower them as this concept may be assumed as a transversal key competence that enables the acquisition of other skills, as the European Commission has broadly defined it. Games can be a way to promote a critical and creative use of the ICT to achieve goals that may be related to health, work, leisure, learning, inclusion, and participation in public life.

The games may enable self-learning by providing meaningful active learning experiences (Costa and Veloso 2015), as well as embody mental and emotional representations. Digital games can improve the quality of life of the elderly in particular with regard to reaction time, visual perception, and eye-hand coordination (Green and Bavelier 2007; Bialystok 2006). Previous research demonstrated that these benefits are related to increased dopamine levels in the brain,

which decline with age, and are elicited by digital games (Green and Bavelier 2007; Parra 2013).

Exergames can be used to motivate older adults to engage in healthy activities in a positive way. These games are designed in order to prevent physical decline and preserve and even physical abilities such as muscle strength and balance (Parra 2013). Serious games can stimulate cognitive functioning skills that positively affecting psychological wellbeing (Parra 2013). Monitoring applications can also be used to analyze user's behaviors such as reaction time, short-term memory, and discernment. These applications inform the doctor of the evolution of the elderly's performance over time, allowing planning or adjusting therapies that may improve the psychological wellbeing.

Conclusion and Discussion

Games have the capacity to improve quality of life of elders and contribute to their active aging. The dimensions of health, participation, security, employment, independence, autonomy, and integration are promoted by the use of games, fostering lifelong learning through digital inclusion. Stimulation of cognitive, sensory, and physical abilities can be achieved with tangible and nontangible interfaces. The learning curve is also an important factor that supports the evaluation of the elderly. Gaming can be an integration tool and not necessarily a therapy, as it can also be integrated in the context of health.

Cross-References

- ▶ Game-Based Approach
- ▶ Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay
- ▶ Games for Health
- ▶ Health Games
- ▶ Serious Games

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Games and the Magic Circle

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Synonyms

Playground; Play space

Definition

In the context of games, the magic circle is the area within which the rules of the game apply, a special space, ideally but not necessarily demarcated by the rules within which play occurs. It need not be a physical space, but can instead be virtual or a frame of mind.

Introduction

The magic circle is a concept still widely used and referenced by games studies scholars and games designers and is both helpful shorthand and a problematic theory. This entry will look over the history of the concept and explore the issues and controversies it raised, with a particular eye toward games studies' frequent criticism of the concept. Despite its contested and controversial nature, the magic circle borders on other central concepts of games studies and games design including play, immersion, and suspension of disbelief, and these linkages are also something this entry will explore.

History

The magic circle was a term first used as part of Johan Huizinga's seminal study of play, *Homo Ludens*. While it is only mentioned only a few times in the English translation of this text, it is regarded as a primary metaphor for how play occurs, as explained when the term is first used:

> All play moves and has its being within a playground marked off beforehand either materially or ideally, deliberately or as a matter of course. Just as there is no formal difference between play and ritual, so the "consecrated spot" cannot be formally distinguished from the play-ground. The arena, the card-table, the magic circle, the temple, the stage, the screen, the tennis court, the court of justice, etc., are all in form and function play-grounds, i.e. forbidden spots, isolated, hedged round, hallowed, within which special rules obtain. All are temporary worlds within the ordinary world, dedicated to the performance of an act apart. (Huizinga 1955: 10)

It is important to note here that Huizinga sees play as behavior distinct from the everyday norms of society, but does not ascribe triviality to play – hence why lawcourts are as valid play spaces as card tables or magic circles.

Huizinga's seeking out of play spaces was also grounded in the discourse of cultural studies, far from actual game design practice, as Calleja's discussion of the concept makes clear (Calleja 2012). This is why the magic circle concept most usually used in games studies in particular is just as much rooted in Katie Salen and Eric Zimmerman's definition and retooling of Huizinga's concept in their 2004 book *Rules of Play*, one of the first major games studies textbooks and a substantive games design resource. To Salen and Zimmerman, the magic circle is a potent metaphor of real use for game designers. They first define the concept in a way similar to Huizinga but assert that the physical element of the spatial magic circle is not mandatory:

> In a very basic sense, the magic circle of a game is where the game takes place. To play a game means entering into a magic circle, or perhaps creating one as a game begins. (Salen and Zimmerman 2004: 95)

Later in the book, they also discuss the magic circle as a form of boundary but also a kind of special space or context for the game created by the player:

> Beginning a game means entering into the magic circle. Players cross over this boundary to adopt the artificial behaviors and rituals of a game. During the game, the magic circle persists until the game concludes. Then the magic circle dissolves and players return to the ordinary world. (ibid: 333)

Salen and Zimmerman's magic circle reinforces the view that games create their own contexts, so that the differences between a person's playing with a physical game piece while not playing a game with it and doing so during a game session is brought into stark relief, since there is now a magic circle operative.

State of the Concept

The magic circle concept sits in a useful place for introducing games as objects of study and is an extremely accessible gateway to more complex concepts such as liminality, presence, the suspension of disbelief, and the lusory attitude (Suits 1978). It also functions as a useful metaphor for game designers to discuss games and their

potential while enshrining a degree of ambiguity about the space where rules, play, and gamers collide.

Ever since Salen and Zimmerman's definition of the magic circle, the term has not been off the radar of games studies academics, who frequently question, dismiss, or attempt to redefine it. As such, using it in an unqualified fashion is not advisable to games studies students new to the concept.

Issues and Controversies

Attacking and interrogating the magic circle concept was so prevalent for a time in games studies that there was even a conference in 2005 convened around "breaking the magic circle." Zimmerman quips when looking back over the history of games studies since *Rules of Play* was published that:

> It seems to have become a rite of passage for game studies scholars: somewhere between a Bachelor's Degree and a Master's thesis, everyone has to write the paper where the magic circle finally gets what it deserves. (Zimmerman 2012).

Scholars generally have two principal problems with the magic circle concept – either that the circle's boundaries are permeable and things can travel through them both ways or that the magic circle concept is reductive, outmoded, or unhelpful and would be better left behind. The idea of a privileged space where gameplay occurs also makes the figure of the critic awkward. Can a critic stand outside the magic circle and meaningfully comment on what goes on on the other side of the boundary?

For some critics coming from particular areas of games studies such as gamification or educational games, the very concept of a magic circle is unacceptable, as the texts with which they are concerned constantly strive to handle the transition between in-game and out-of-game information, be it advertising material or learning curricula.

The magic circle's ambiguity and its imperfection as a game system model drives other critics who would see it removed or replaced. The awkwardly inexplicable "magic" of the circle (and it is no accident that Huizinga chose the magic circle, rather than the other playgrounds he lists, as emblematic, since "magic" implies a tangible link to ritual spaces) which centers around the self-reflexivity of play is where Klabbers (2009) situates arguments for renovation of the concept best articulated and discussed in a critique by Myers (2012).

Other criticisms run the gamut from the explicit link to ritual which persists in the "magic" element of the phrase, its growing irrelevance as an increasingly networked society spends time often in parallel virtual and non-virtual spaces, or its implied dichotomy between work and play through to the value of the pragmatic approach to the concept taken by Salen and Zimmerman in their redefinition. The existence of magic circles around digital games in particular, where possible play actions are often unalterably authored into the system, is often challenged (Calleja 2012).

While there are many perceived and well-articulated problems with the concept, a majority of the papers written on it fall into the trap of attempting to replace the magic circle with a system of their own design, while more considered scholarship (Consalvo 2009) suggests the adoption of sociologist Erving Goffman's broader approach of frame analysis in its place. Many other critics try, if not to replace the concept wholesale, then to repair it in order to make up for perceived deficiencies. Castronova takes up the concept's permeability as a virtue, seeing markets, politics, and law pass in and out through what he redefines as a "membrane" thrown around the text by the magic circle. He still eventually declares that, at least in the case of the MMO-RPGs which he is discussing:

> What we have is an almost-magic circle, which seems to have the objective of retaining all that is good about the fantasy atmosphere of the synthetic world, while giving users the maximum amount of freedom to manipulate their involvement with them. (Castronova 2005: 159–160)

In the retrospective cited above, Zimmerman himself takes responsibility from Huizinga for the controversial redefinition of the magic circle, but defends the concept as a worthwhile game design metaphor, rejecting the way it has been read by

many as a hard boundary hiving games off from the outside world. He does this while pointing out the exaggerated way many of the critics of the magic circle style their offerings to attack straw man arguments instead of actually focusing on the perceived deficiencies of the magic circle. While it is not an ideal metaphor, he contends, the kind of reductive formalism which it has been linked to does not really exist in scholarship, the concept is generally accepted as what it is – an imperfect metaphor.

Other games studies academics are more embracing of the core ideas represented by the magic circle and suggest not their own interpretations of the concept nor its replacement, but rather actively seek to repair it. In his response to various magic circle controversies, Jesper Juul defends the idea of the magic circle as a boundary, but sees it as potentially an awkward metaphor. His suggested replacement is the idea of a puzzle piece:

> Perhaps the problem with the magic circle *as a metaphor* is that it suggests a uniform interface between the game and that which is around the game. We could alternatively describe a game as a puzzle piece. This makes it easier to talk about some of details surrounding games: a puzzle piece has different interfaces on its sides. Seen as a puzzle piece, a game may or may not fit in a given context. We can then analyze *how* a game fits into a context, no longer arguing *whether* games are separate or not. (Juul 2009: 8)

Like Zimmerman, Juul also sees the controversies around the concept as overblown and points toward academics' tendency to seek out and challenge binary dichotomies, often for short-term political ends as partly culpable for the sheer amount of criticism and debate the concept has received. His is possibly the most accepted rehabilitation of the magic circle metaphor into a tool useful for modern games studies, even if the original concept is of use to games designers and those outside of the scholarly arena.

Conclusion

While the concept of the magic circle is undoubtedly problematic, it also feels core in many ways to games and game studies, and the field would certainly be weaker without both it and the debate which its prominence has engendered. The idea of magic circles, be they bounded off playgrounds or chalk lines on the ground generating a special place in time and space where gameplay happens, is enticing, but also extremely broad and open to interpretation. Drawing attention to the border regions of games can be worthwhile, as shown in the context of social, material, and cultural elements by Stenros (2014) in a fruitful paper also trying to rehabilitate both Huizinga and Salen and Zimmerman's magic circles and show that the concept(s), ambiguities, and all hold a place in the modern games studies lexicon.

Cross-References

- ▶ Immersion
- ▶ Telepresence
- ▶ Virtual Worlds

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Games for Change

▶ Hypermedia Narrative as a Tool for Serious Games

Games for Health

▶ Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay
▶ Transformational Games

Games in Science

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Synonyms

Citizen science; Crowdsourcing, scientific games; Educational games; Games with a purpose

Definition

Games in Science are used for scientific purposes, like crowdsourcing scientific problems, collecting data from gamers, educating the gamers, or gamifying science itself.

Introduction

Games are not only used for entertainment but also for several serious purposes. Academia has used games for research and knowledge generation as well as for teaching and knowledge transfer. It has been proven that some complicated scientific problems can be solved much better by human players than algorithms. If it is possible to transfer a problem into an entertaining game structure, it could possibly be crowdsourced to a worldwide gaming community. Motivated by game mechanics and the higher purpose of helping science, many players have invested a tremendous amount of time in these games.

One of the most popular examples of this strategy is Foldit, an experimental computer game in which the player folds protein structures as perfectly as possible. The game has been developed in 2008 at the University of Washington. The best scores are analyzed by experts. In 2011, Foldit players helped to decipher the structure of the Mason-Pfizer monkey virus in only 10 days. The problem had remained unsolved for 15 years before (http://fold.it/; Cooper et al. 2010). Science Games like these are not only simulations but actively include game elements like points, badges, and leaderboards to engage players. Science games like these are useful in every field in which humans outperform algorithms (Hand 2010).

Citizen science games are created equally to allow gamers to actively participate in research as to raise interest and awareness about science-related topics. An example of a citizen science project in which citizens are helping researchers is Galaxy Zoo, created by a university collaboration between Oxford, Portsmouth, and Johns Hopkins. Over 150,000 players have helped to classify unknown galaxies within only a year. Researchers could not have done this work in years that players achieved in under a month. By now, there are many projects within Galaxy Zoo following different astronomical cartography goals (https://www.galaxyzoo.org/).

Another area of Games in Science is covering games that are built to generate data about the players while being played (Raykar et al. 2010). A well-known example is NeuroRacer, which was developed in 2013 by the University of California. The player has to multitask, as he is steering a car while he has to react correctly to some color codes shown. The graphics of the game were very simplistic, as the game was relying fully on the mechanics. The game was used to measure the effect of

game-based multitasking training for elderly test subjects with an EEG (https://neuroscape.ucsf.edu/technology/#neuroracer). Although the results of the study were questioned later, it became a well-known example of how to create experiments with video games and measure the training effect of gaming to the brain (Abbott 2013; Anguera et al. 2013).

A growing field that is called Science Games is covering games for teaching, experimenting, and education. A well-known example is A Slower Speed of Light, developed in 2012 at the MIT Game Lab. It aims to teach the player about the relativity of space time, as the game setting alters the speed of light. The player is supposed to collect a number of objects in a three-dimensional setting, and with every object the speed of light is lowered. This way a very complex topic of physics is made tangible and experienceable for a broader audience (Kortemeyer et al. 2013).

But also existing games that were built mostly for entertainment are used for scientific purposes. In the very popular game Minecraft, players can create their own architectures, machines, and structures by crafting and building blocks (https://education.minecraft.net/). This game has been used as a basis for project Malmo, which is an artificial intelligence experimentation platform. With this open-source platform, researchers can set experimental AIs into the world and observe how they learn to collaborate and interact with each other or human players. This way solutions can be tested and compared and allow for the integration of a huge base of human players. Minecraft has also been used for teaching in an engaging way. In a special educational edition, topics like math, physics, history, humanities, or computer science are integrated in a playable way (https://www.microsoft.com/en-us/research/project/project-malmo).

Cross-References

- ▶ Augmented Learning Experience for School Education
- ▶ Gamification and Serious Games
- ▶ Gamification in Crowdsourcing Applications
- ▶ MEEGA+, Systematic Model to Evaluate Educational Games

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Games Industry

- ▶ Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

Games User Research

- ▶ Player Experience, Design and Research

Games with a Purpose

- ▶ Games in Science
- ▶ Gamification in Crowdsourcing Applications

Gamification

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Synonyms

Applied gaming; Funware; Ludification; Playful design

Definition

Gamification is the intentional application of game elements to nongame contexts, with the intention of creating playful experiences or gameful interaction. It is often used to motivate and increase user activity or user retention.

Introduction

A synthesis by Seaborn and Fels (2015, p. 17) that considers seminal works on gamification (Deterding et al. 2011; Huotari and Hamari 2012) defines gamification as the "intentional use of game elements for a gameful experience of non-game tasks and contexts." In this gamification is different from serious games, which involve the use of full games in serious, nongame contexts.

Gamification has been used to increase engagement in education (Auvinen et al. 2015), compliance and satisfaction in healthcare (Stinson et al. 2013), user activity in sharing economy (Hamari 2017), and quality and performance in crowdsourcing (Liu et al. 2011; Massung et al. 2013). Currently most common fields for applying gamification are e-learning, sustainability, and motivational software (Kasurinen and Knutas 2018). Successfully applied example from the mobile application industry is the "Run, Zombies!" exercise game, which uses the storyline of running away from monsters to help the player regulate their pacing when running. Additionally, the player can collect virtual supplies for the game's home base while jogging. Another example from city design is musical stairs, which combine fun and curiousness to encourage people to use the stairs instead of the escalator.

The use of gamification often involves the use of common game design elements, such as stories, rules, goals, feedback, and tiers. However, in successful gamified design, user experience is more important rather than the visual manifestation of certain elements (Deterding 2014). Just like in game design, in gamified design the system has to be considered in its entirety from the perspective of the user, instead of adding a set of elements, such as points or badges.

Gamified design and gamification has also faced critique, especially in cases where a stock approach of gamification has been added on top of an existing system in so-called "pointsification" (Kapp 2012). However, gamification has potential for successful results if the system is selectively designed, allowing for personalization and customization, in order to accommodate individual users, and if the design is informed by end users' intrinsic motivators (Seaborn and Fels 2015).

Theoretical Foundations

The dominant theoretical framework for gamification is currently Self-Determination Theory (SDT), as developed by Deci and Ryan (2000), and the most common design theory is user-centered design (Seaborn and Fels 2015). In user-centered gamification design, the main priority is providing an experience for the user and designing with the user's needs and desires in mind (Nicholson 2012). Theoretical frameworks for gamification that follow self-determination theory (e.g., Aparicio et al. 2012) posit that effective gamification is about using game elements to support users' innate need to seek out novelty and challenges, or intrinsic motivation (Ryan and Deci 2000). These three principles according to SDT are:

- Relatedness: the universal need to interact and be connected with others.
- Competence: the universal need to be effective and master a problem in a given environment.
- Autonomy: the universal need to control one's own life.

Design Frameworks for Gamification

There have been several gamification frameworks published, of which Deterding's Method for Gameful Design (Deterding 2015) is one of the most recent and most comprehensive. It is based on the Player Experience of Need Satisfaction (PENS) model, which is based on self-determination theory. First the method uses PENS to analyze what players find motivating and enjoyable qualities in gameplay. Then, it provides a framework to examine gameful design through elements of interconnected challenges, in which the player is taking actions in pursuit of goals, within the system's rules. It posits that gameful design should use the skill-based challenges that already are inherent in the activity that the gameful design supports, with a data-driven design process guided by iterative prototyping.

Two other often used gamification design frameworks are for education (Kapp 2012) and business (Werbach and Hunter 2012). Kapp's approach for education is partly inspired by serious games (Deterding 2015), and Werbach and Hunter's pattern-based approach is intended for motivating users of business platforms.

Conclusion

Gamification is a powerful technique for engaging users through gameful and playful design, supported by a thriving multidisciplinary field and an increasing number of design theories and frameworks (Nacke and Deterding 2017; Seaborn and Fels 2015). However, it is not an easy approach or a one size fits all approach. Care should be taken when choosing design elements and designing for user experience.

Cross-References

- ▶ Augmented and Gamified Lives
- ▶ Augmented Learning Experience for School Education
- ▶ Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being
- ▶ Domain-Specific Choices Affecting Design Effort in Gamification
- ▶ Game Thinking X Game Design Thinking
- ▶ Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay
- ▶ Gamification and Serious Games
- ▶ Gamification in Crowdsourcing Applications
- ▶ Gamification of Modern Society: Digital Media's Influence on Current Social Practices
- ▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums

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Gamification and Serious Games

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Synonyms

Game-Based Learning (GBL); Interactive learning events; Mixed reality serious games; Simulations

Definition

A *video game* is a mental contest, played with a computer according to certain rules for amusement, recreation, or winning a stake (Zyda 2005).

A *digital game* refers to a multitude of types and genres of games, played on different platforms using digital technologies such as computers, consoles, handheld, and mobile devices (DGEI 2013). The concept of digital games embraces this technological diversity. In contrast with terms such as "video games" or "computer games," it does not refer to a particular device on which a digital game can be played. The common factor is that digital games are fundamentally produced, distributed, and exhibited using digital technologies.

Gamification has been defined as the use of game design elements in nongame contexts and activities (Deterding et al. 2011), which often aim to change attitudes and behaviors (Prandi et al. 2015). Using game-based mechanics, aesthetics and game thinking to engage people, motivate action, solve problems, and promote learning (Kapp et al. 2013; Kapp 2015), i.e., employing awards, ranks during missions, or leaderboards to encourage active engagement during an activity, e.g., health fitness tracking or e-learning during an online course. Thus, gamification uses parts of games but is not a complete game.

Serious games are full-fledged games created for transferring knowledge (Ritterfeld et al. 2009), teaching skills, and raising awareness concerning certain topics for nonentertainment purposes (Deterding et al. 2011). Essentially is a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives (Zyda 2005).

Introduction

The appeal of *mixed reality* (MR) digital games arouses interest among researchers and education specialists who since their recent proliferation have been trying to introduce their motivating

potential in learning contexts. Previous work in this field has been focusing on whether digital games can, via novel presence (feeling of "being and doing there" in a virtual or augmented world) and MR gamification (dynamics, mechanics, components), support and foster future learning and teaching, to address a wide variety and variation of educational contexts. The final aim is to provide informal, nonformal, as well as formal learning for their end users.

This entry aims to highlight their main conceptual differences and key indicative applications and challenges across the mixed reality and learning aims.

Related Ecosystem Definitions and Key Application Areas

The concept of "*presence"* refers to the phenomenon of behaving and feeling as if we are in the virtual world created by computer displays (Sanchez-Vives 2005). "Presence is an incredibly powerful sensation, and it's unique to VR; there's no way to create it in any other medium. Most people find it to be kind of magical" It is not the same as "immersion," where the user is simply surrounded by digital screens (Abrash 2014). Presence is a key term that next-generation of serious-games will need to take into careful consideration to be successful.

Mixed reality (MR) has been defined as a continuum of technologies that include both virtual reality (VR) (fully substitute reality with a virtual 3D world) as well as augmented reality (AR) (supplements reality by blending virtual and real elements with the use of special displays) (Azuma et al. 2001).

Simulation is a realistic, controlled-risk environment, where learners can practice behaviors and experience the impacts of decisions. Simulations are designed to be realistic representations of real-world environments, events, and processes, whereas games on the other hand may or may not reflect the reality. Hence, Simulation + Gamification = Game (Kapp et al. 2013).

Digital Games for Empowerment and Inclusion (DGEI) are Digital games for nonleisure purposes used in specific contexts so that they can empower individuals and communities in ways that lead to social inclusion (Misuraca 2012).

Interactive Learning Events (ILEs) is a term used to include games, gamification, and simulation (Kapp et al. 2013).

Informal learning: Learning without the intention to learn and without actual planning of learning activities. Sometimes also referred to as experiential or accidental learning.

Formal learning: Learning as an intended and planned activity taking place in an organizational context.

Nonformal learning: Learning as a result of planned general activities in which participants can learn both intentionally and unintentionally (Misuraca 2012; Centeno 2013).

Mixed Reality Serious Games and Gamification (MRSG) is used about any kind of serious game, simulation, or gamified process for learning in mixed reality featuring presence, natural interaction, and the suite of the novel MR technologies, MR gesture-based and game-based learning (Zikas et al. 2016).

Indicative nonentertainment themes of serious games and gamification include multitude areas from general education and training (Magnenat-Thalmann et al. 2009) to cultural heritage (Anderson et al. 2009; Kateros et al. 2015; Ioannides et al. 2017), health and surgical training (de Ribaupierre et al. 2014; Papagiannakis et al. 2018), and inclusive well-being (Brooks et al. 2014).

Challenges

One of the main challenges for the next-generation of gamified simulations and serious games involves answering the key research question on *how allow the learners and teachers to experience the feeling of "presence" under a novel MR educational learning framework*, in both virtual reality (VR) as well as augmented reality (AR) formal, nonformal, and informal learning environments. The former (VR) allows for the unique feeling of "being there" and "doing

there" in the virtual world, that will be transforming the overall game-based learning experience, via latest innovations as well as recent progress in low-cost h/w head mounted displays (HMDs). The latter (AR) blends real and virtual elements so that the 3D virtual element is registered accurately in the real world and interacted freely by the learner via various mobile displays, including smart glasses, natural, gesture-based interaction (mobile RGB and RGB-D), MR virtual characters (Vaccheti et al 2004, Magnenat-Thalmann et al. 2009; Jung et al. 2011), and gamified learning processes (Sawyer 2002; Misuraca 2012; Centeno 2013).

Another main challenge for serious-games and gamification involves user-performance metrics, characterization of the player's activity, and better integration of assessment and user analytics in games (Bellotti et al. 2013). "[Serious games] will not grow as an industry unless the learning experience is definable, quantifiable and measurable. Assessment is the future of serious games" (Ritterfeld et al. 2009). In MR, this challenge requires significant future research, but it can be aided by the fact that the end-user position, orientation, gaze, gestures, and actions can be fully tracked and recorded in VR/AR.

Conclusion

In this entry, we have provided clear definitions and latest bibliographical references for the terms serious games, gamification, simulations, digital games, and related terminology suitable for mixed reality continuum. Moreover, we have provided key future challenges that their application in the mixed reality continuum poses.

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Gamification and Social Robots in Education

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Synonyms

Embodiment; Interactive learning; Social robots

Definition

The term gamification originated in 2008 and became a part of the game design and digital media design industry lexicon in late 2010. Gamification involves using elements found in game design and applying them to contexts outside game design. A social robot has two parts: a physical presence that interacts with people and a cyberphysical system that is connected to cloud services. Social robots can be designed to behave like humans in limited ways. By using sensors, actuators, and internal systems to speak, make gestures, move, make eye contact, change color, and generate sounds, social robots can demonstrate emotions like joy, sadness, and boredom.

Introduction

Gamification and social robots describe the combination of these two elements to increase levels of motivation and engagement in the first instance, and increase adoption intentions and positive perceptions in the second. Since both gamification and robot design elements – as separate paradigms – have been shown to affect human attitude, researchers believe that the combination of the two paradigms will have a stronger effect on human behavior and attitude.

Social Robot Gamification

The combination of gamification and social robots was attempted in an educational context to increase engagement, motivation, and enthusiasm in self-learning and teacher-led environments (Alsebayel and Berri 2019; Donnermann et al. 2021). Education is a major area used to study the effects of gamification, and research has demonstrated that gamification has a positive influence on students and the learning experience (Hakulinen et al. 2015).

Gamification Elements

In educational environments, four game elements are particularly important in the gamification context: (1) points, (2) badges, (3) levels, and (4) leaderboards.

Points are the foundation of all games. In the gamification educational context, these elements provide feedback for good conduct and report student progress (Sailer et al. 2017).

Badges are realized achievements. It consists of a name, an icon (e.g., an image of a gold cup, medal, or other award), and an achievement description (Hamari and Eranti 2011). Badges give positive feedback and mark work accomplishments – just like points. They also can increase engagement by motivating players to develop game and/or level objectives.

Levels. The three important level types in gamified systems are the following: (1) game levels, which gradually rise in difficulty; (2) playing levels, which is a level a player may select; and (3) player levels, which can be attained after the player gains enough experience points. Achieving a new level in education gamification systems is used as a reward for learners that persevered with assignments and tasks (Nah et al. 2014).

Leaderboards show basic, similar achievements where users can compare their performances, points, and badges.

Social Robot Options

The suggested role a social robot should play in gamification systems is that of a tutor. This is based on the ideas found in self-determination theory (Donnermann et al. 2021). Social robots that are suitable for this role can be purchased commercially or custom designed. The type of robot used in the gamification system depends on the rationale for its use.

Commercially available social robots may have a significantly larger feature set than a custom-built equivalent. One example is the type of expressions a commercially built robot can express and detect in humans. Depending on the make, robots such as Reeti, Nao, and Pepper may have faces, heads, eyes, hands, or legs that possess high degrees of motion. Built-in text-to-speech and voice recognition capabilities enable the robot to read prescripted text, ask questions, and understand the learner's response. These types of robots can also announce achievements and learner points, which is more interactive and engaging than simply having such information displayed in text form on the computer screen. Additionally, before entering the market, commercially available social robots undergo multiple HRI studies in settings that reflect target use cases like elder care, education, and healthcare. This level of testing assures researchers that the social robot can reliably function in similar settings. This allows researchers to focus on higher-level social interactions in their studies including the robot's effect on motivation, engagement, and enthusiasm in learners instead of lower-level interactions such as interface interaction, perception, and user response.

Custom-built social robots. In the study by Alsebayel and Berri (2019), the custom-built social robot was integrated with the gamification system. The robot had three emotional expressions: happy, sad, and resting. It could also blink its eyes and move its head. Given the reduced features and capabilities typical of custom-built robots, their use should be constrained in gamification and social robot studies. Examples of when to use a custom-built social robot may include the following: the need for local or regional accents, parochial appearances, or traditions that are integral to the learner's experience.

Social Robot Gamification Configurations

There are three possible gamification and social robot configurations. Two of these configurations have been used in the literature by Donnermann et al. (2021) and Alsebayel and Berri (2019). However, no work has been done to date using the third configuration. Details on the three configurations follow.

Robot not integrated with the gamification system. In this configuration, the social robot is used with the gamification system, but there is no integration of the robot with the gamification system. Such a configuration allows researchers to investigate the effect the social robot and the gamification system have on enthusiasm,

motivation, and attention as separate, and then as combined systems. However, a potential shortcoming of this configuration is that because the robot and the gamification system are not tightly integrated, navigating the systems may become challenging for the learner when both are in use. Donnerman et al. (2021) reported the unexpected result of increased distraction when both systems were in use.

Robot integrated with the game in the gamification system. In this configuration, the robot is integrated with the game that runs within the gamification system. The degree of integration is limited to data sharing, where the robot acted as an embodied user interface that indicated whether the user's response was right or wrong. The robot possessed no ability to detect human expression, and no other social factors were captured or used to affect the game. The game itself kept track of the correct responses and provided opportunities for the learner to correct their mistakes. There were no other gamification elements in the system beyond score keeping and game levels.

Robot embodies the gamification system. To date, no research has been done using this configuration. As a result, there are many research questions, including:

(i) To what degree should the robot embody the gamification system?
(ii) What gamification elements should be implemented?
(iii) How should the robot's appearance and behavior reflect the gamification elements?
(iv) How do these factors affect learner motivation, enthusiasm, and engagement?

Conclusion and Discussion

Research in gamification and social robots as a method for increasing motivation, engagement, and enthusiasm of learners in an educational setting has so far produced inconclusive results. This is because there are few studies done in the area to date. Besides replicating, or repeating, experiments were done in Alsebayel and Berri (2019) and Donnermann et al. (2021), whose work was done using two of the three gamification configurations: (i) robot combined but not integrated with the gamification system and (ii) robot connected to the game in the gamification system. There are many opportunities for research to be done in the third configuration option where the social robot embodies the gamified system.

Cross-References

- ▶ Augmented and Gamified Lives
- ▶ Challenge-Based Learning in a Serious Global Game
- ▶ Gamification
- ▶ Gamification and Serious Games
- ▶ Gamification Ethics
- ▶ Gamification in Crowdsourcing Applications
- ▶ Incremental Games
- ▶ Serious Online Games for Engaged Learning Through Flow

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Gamification Ethics

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Synonyms

Dark side of gamification; Ethical issues in gamification; Ethics in gamification

Definitions

Gamification ethics refers to the study and understanding of right and wrong conducts by or with gamified solutions. As gamification taps into the natural playfulness of human beings, ethical issues are prevalent and must be considered by the developers.

Introduction

The term "gamification" usually refers to applying game design elements into nongame contexts (Deterding et al. 2011). Typically, it is used to improve the motivation and performance of the players to tasks like learning, well-being, rehabilitation, or work efficiency. For example, Hamari et al. (2014) show how gamification can improve the players' motivation in possibly arduous and boring tasks.

The road to gamified solutions has often been paved with good intentions where designers, developers, and funders are aiming at improving the players' quality of life. However, even projects that have been developed with good intentions may end up in creating ethically questionable or even clearly morally wrong solutions. This reminds of the statement attributed to Albert Einstein according to which if he would have known how atomic power was to be utilized, he would have preferred to become a watchmaker instead of a scientist.

As gamification touches the very basics of the playful nature of humanity, the designers and developers of gamified solutions can either through pure mistakes or with evil intentions create products and services which either endanger or worsen the condition of the players, the environment, or the society. Whereas it is hard to enlighten developers with bad intentions, it is crucial for the developers of gamified solutions with good intentions to understand the ethical challenges inherent in the used techniques.

The main things for a developer to keep in mind regarding ethics, on top of their own intention – which of course ought to be the good of the stakeholders of the application – are that the applications are built in a just manner and that the consequences benefit the client, the users, and the targets of the systems being designed (Moor 1999). Even though most developers consider themselves to be good people, as Don Gotterbarn always reminds us, they should also be aware that if they do not actively look after their character traits related to their work in a virtuous manner, they do not always act as they ought.

Based on the theoretical ethical principles, applied ethics aims at tackling a certain area. The ethical questions raised by gamification techniques have only recently gained interest with the works of Bui et al. (2015), Hyrynsalmi et al. (2017a, b), Kim and Werbach (2016), and Sicart (2015). The field remains still largely unexplored, yet further studies are published with an increasing pace.

While our aim here is to provide a broad overview of ethical problems of gamification, this is not a comprehensive list of all possible issues. As both the field and the techniques are still evolving, new ethical questions are expected to pop up and some of the older topics will become outdated with the new systems.

Our intention in this entry is to give an introduction to the ethical problems present in gamification. In the subsequent sections, we divide gamification ethics into three broad groups:

ethical problems related to the *design* of gamification, ethical problems related to the *technology* used in implementing gamified systems, and ethical problems related to the *data* utilized by gamified systems.

Issues on Gamification Design

The design phase includes activities typically carried out before and during the implementation of a gamified system. While gamification aims at improving the players' interests on virtuous issues and tasks, there are examples of using it for malevolent purposes such as stealing or damaging CCTV cameras or even prompting players to commit suicide (Hyrynsalmi et al. 2017b). Omitting such extreme examples, there are, however, solutions that are either legal but questionable or that have been developed with good intentions whereas their consequences are ethically questionable. For an overly simplified example, a gamified solution for a nurse, paramedic, or firefighter could, in theory, improve their job satisfaction; however, every second spent on secondary purposes, such as gaining points in a gamified environment could, literally, endanger someone's life or property in these kinds of contexts. The basic design question one should always ask first is: does gamification work in this particular context?

From the perspective of gamification design, we can recognize two general groups considering the implications on an individual person and on the impacts on a society.

Personal

Gamification overloading is a rarely addressed topic in design. An average player is likely advance only in few different games at the same time. The average player does not play several massively multiplayer online games simultaneously due to the cognitive burden caused by keeping up several different tasks, stories, and game mechanisms. The same cognitive limits apply also to gamified solutions. Would an average gamification player be able to simultaneously keep up with gamified electricity saving, physical exercise, and educational solutions? Thus, designers should also ask whether gamification brings long-lasting value in the particular context or whether it would turn against its objective due to potential overload.

Individual players cannot be handled as a homogeneous group. For instance, let us consider the case of an individual who is a game addict. Should he or she be exposed at his or her workplace to a gamified system? If not, would he or she be in a different, possibly weaker position than others? A similar kind of though experiment could be carried out with underaged pupils (e.g., educational gamification), elderly, or cognitively challenged users.

Societal

Employees can deliberately fake information on gamified system, for example, to use the leaderboard to advance their position in salary negotiations (Callan et al. 2015). Cheating in general is a likely problem, if the gamified system has real-world benefits that can be gained. Moreover, tapping into the competitive drive of the players of a gamified system can have destructive consequences on the work environment as the competition leaks from gamification into the real world.

Technology-savvy younger players might have an advantage in using gamification because of their familiarity of game mechanics from entertainment games.

Putting the participants in an equal starting position is a hard problem to solve, which is tackled by game balancing in game design (Adams 2014, pp. 403–405). A balanced game is fair, meaning that all players have an equal chance of winning at the start, and it should be appropriately challenging (i.e., not too hard nor too easy) for the players. The skill in the actual task of the player, rather than in the game created on top of the tasks solved through gamification, should be the most important factor in determining the player's success.

Furthermore, it is possible that the setup or the story in a gamified system favors a majority of the players, ignoring the (gender or ethnic) minorities' interests or values. In a workplace situation,

this might even enforce the existing and possibly hidden attitudes and prejudices.

The motivation behind gamification can be, in some cases, hidden from its players. For example, the design of the game *Ingress* – developed by Niantic, a company spun off from Google – is assumed to have originally been motivated to gather location information to improve Google's map services. From this commercially motivated example, we can draw a parallel to Sesame Credit – developed (via affiliates) by the Chinese on-line marketing conglomerate Alibaba and the Chinese government – where the design motivation is, at the same time, both commercial and political.

If gamification is used for political purposes, it opens the possibility for using it as a tool for propaganda and surveillance. The ethical implications of this are manifold: conventional values such as "harmony" in the society are typically enforced, a lack of revolutionary and thus society-enhancing ideas can follow. And, of course, there are clear risks for the privacy of the players. Just think of Stasi (*Staatssicherheitsdienst*) or similar organization gamifying their surveillance of the citizens, or gamifying catching illegal immigrants entering the country – one can be of the opinion that illegal immigrants ought not to enter the country, but would it really be a good idea to make this kinds of consequences to actual living, breathing, and feeling human beings into a *game*?

Compromising the Underlying Technology

The technology used in gamification should protect the players' sensitive information and allow them to decide how the information is used (cf. Lahtiranta et al. 2017). Moreover, it should provide a fair playing field for players and prevent any kind of cheating. These attributes can be compromised by attacks utilizing either technical or social weaknesses. For example, passwords can be stolen by cracking them (technical attack) or pretending to be administrator and asking the players to give their passwords (social engineering attack).

The technical attacks can be directed to the clients, the servers, or the network connecting them (Smed and Hakonen 2017, pp. 290–291). An attack can take place over (e.g., reading pixel values from the user interface), under (e.g., hacking a driver), or in the client (e.g., altering the code in the memory). Apart from physical attacks (e.g., theft), servers are vulnerable to network attacks (e.g., IP spoofing or denial-of-service attacks). Network communication can be compromised by tampering the packets (e.g., intercepting or replicating them or forging their payload data).

The social engineering attacks can include, but are not limited, to blackmail, using the gullibility of the other users, gaining access through pretending to be a superuser – for some reason without superuser access – or bribing others either with joint sharing of results (cooperating against others unfairly) or paying smaller amounts for greater gains (Mitnick and Simon 2003).

The motivation behind the attacks on games can stem from different sources (Consalvo 2007) but broadly speaking, we can recognize three areas:

- Enhancing the gameplay motivated by, for example, lack of skill or time or by boredom
- Playing with the game system to explore and experiment, extend the lifespan of the game, or creating new ways to play
- Extra-game factors such as money, fame, vandalism, or nonconformity

Although any breach of the information security can have severe repercussions to the player, the motivation plays an important role in discerning the possible ethical consequences. Players wanting to enhance they gameplay will, naturally, increase inequality among the other players. A similar situation may ensue even if the players are playing with the gamified system, although their motivation is not directed against the other participants. The biggest threat comes from the last group. When extra-game factors are included,

the other participants will be become expandable and just means-to-an-end.

Use and Scope of the Gamified Data

Gamified solutions generate personal data from the players' personal interests, actions, and habits. Thus, the environment where the gamified solutions are used affects the ethical questions of gamification. In the following, we have identified five environments where intentions to gamify as well as ethical questions differ: healthcare, work life, government, school, and leisure systems.

Healthcare

The healthcare sector is actively looking for ways to improve people's health behavior using technology, and gamification is seen as a promising opportunity. It is possible to imagine a gamified healthcare system provided by public healthcare that drives for a lifestyle change (e.g., to get rid of intoxicants, to get more exercise, or to lead a generally medically reasonable life). We are not criticizing gamification itself as it could be a good tool for many people to achieve these goals, but there are some risks we want to point out that are involved.

The primary concern is that health is an area of life where people can be highly vulnerable, because for many, it is not possible to choose the services they would want, for example, due to financial or geographical limitations. The secondary concerns relate to the data produced with these kinds of solutions: personal health records of any kind are extremely private.

There is a risk that the user could lose the control over the information gathered by the gamified system, if it is also used for larger healthcare purposes. There is a drive to collect medical information for research purposes, which is usually done in good faith. However, we know from examples that the genetic information of entire countries has become tradeable goods, in which individuals have lost control over their data.

Healthcare gamification drives towards a biomedically desirable lifestyle. The personal experience of health, however, is not a biomedical experience but rather an existential experience; what could be called homelike-being-in-the-world (Svenaeus 2001). Hence, what people experience as good health varies from person to person and depends on their personal goals and desires in life.

Work Life

The current work-life environment – riddled with financial crises, work automation, competition in employment – leaves many employees with no possibility to change their employer. Consequently, we are more and more attached to our current employment, and if the environment is gamified, a gamified system in the workplace could force us in an ever-increasing competition against one another. This would turn us into an exploitable "standing reserve" for corporate purposes that would take away considerable parts of our power over our own lives, creating new "rules" and endangering the authentic (self-owned) being in the context of working life (Heidegger 1977).

Nevertheless, there are many employers who willingly take new technologies into work environments with the aim of helping employees to be empowered at work. Such solutions can, for example, be linked to job satisfaction, feedback, or suggestions for improvement. In such data-driven gamified solutions, particular care should be taken to keep hidden the unique characteristics that would help to identify individuals.

Government

Governmental information systems are the tools that are used by government and citizens forming a part of how our society is working and communicating. When thinking about the gamification of government systems, one has to understand that systems can be such that citizens are obligated to use them. Since the idea of gamification is to change people's behavior through information collected through gamification, there is a risk that individuality will be lost and the demand for being an "average" citizen will increase. This should be avoided as it causes citizens to lose their individual life goals and only become

statistics in a government plan; after all, we do have our own desires, hopes, and fears that should be valuable in and of themselves.

In addition, citizens are unlikely to have the ability to know – and even less to control – who uses their information and for what purposes. Another example of problems in gamification is that it could be used to "activate" unemployed citizens. It is often claimed that unemployed people should perform some activities to get their unemployment benefits. However, gamification does not create new jobs but easily becomes just one more duty for those weakest in our society; this does not help them but highlights the lack of power of the unemployed. Since our governmental systems are a vital part of our modern society, it is important to ensure that the privacy and liberties of citizens are secured by the government; otherwise, we risk the foundations and justification of democratic society.

School

For younger people, there is a risk that they may not have the capacity to claim or the will to demand different solutions. When thinking of gamification, pupils lack the power to choose what is used for teaching. This underlines the need to protect their privacy and other related rights, as they have no judicial or practical means to control how gamification and the information collected from them affect them now or later in life.

When we add gamification in education, there is a risk that the division between "good" and "bad" pupils will be emphasized and, as a consequence, the result may be that inequality between children grows. Since pupils do not yet have full rights or responsibilities as adults do, it is our responsibility to safeguard their right and govern their rights as long as they are considered to be equal members of the society. In the case of young people, this means that in adulthood they can decide that they do not want their personal and/or identifiable information to be used; they need to have the right to prevent the use of it and even to destroy information considering them, if they so decide.

Leisure

Gamified leisure is a different matter altogether. Although gamified systems may have an impact on who and what we are in our free time – unless there is a monopoly (or oligopoly) of systems to use – we can always opt out as long as we understand the changes to us the system can make. Nevertheless, we must at least be able to remove our data from the system we have used or tried out, which is a minimum of control requirement.

For instance, we could use sports applications such as heart rate monitors, which these days provided a wealth of additional applications from GPS to following our sleep and beyond. These applications use our data as well as the data of others and gamify the exercise experience. The "100 percent" is likely to be defined, at least in part, by utilizing aggregated user data. The user can, if they want, stop using the system. However, they still have no control over the data already collected, and it can later be used by the application developers as they please.

Summary

This entry highlighted ethical issues embodied in the use of gamification tools and techniques. As gamification touches on the very basic nature of humans, it is important for the designers and developers of gamified solutions to understand the ethical ramifications of the decisions on design, technology, and data.

While our aim was to bring gamification ethics into public discussion and extent the awareness of possible pitfalls, we are not advocating avoiding gamified solutions altogether. Rather, we encourage designers, developers, and funders to actively utilize the best of gamification techniques for the best of humankind while still minding the ethical considerations.

Cross-References

▶ Games for Change
▶ Games for Health
▶ Gamification

- ▶ Rehabilitation Games
- ▶ Serious Games

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Gamification in Crowdsourcing Applications

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Synonyms

Collective intelligence; Crowdsourcing: user-generated content; Games with a purpose; Gamification: ludification; Serious games; Social collaboration; Virtual volunteering.

Definition

Gamification is generally defined as the use of game design elements in non-gaming contexts. Crowdsourcing is understood as the process of obtaining content and/or services by involving contributions from a large group of people, in particular from an online community. The use of gamification techniques in crowdsourcing applications is mainly due to the need of involving and engaging more users and of improving their experience.

Introduction

In recent years, new forms of game and game technologies have emerged in the fields of industry and academia research. In particular, it is evident in the growth of serious and pervasive games. In this context, a new trend, called "gamification," has reached and won many sectors, including the business and the marketing domains (Seaborn and Fels 2015). Such a new trend essentially uses game design and elements with the aim of improving users' experience and increasing users' involvement in services and applications which are not games (Deterding et al. 2011). Its goal is explicitly different from the merely users' entertainment.

It is worth noting that gamification is not a new issue, but it can go back to marketing activities and techniques (i.e., points cards and rewards memberships), usually exploited to engage clients, by creating or enforcing loyalty in a product or in a brand (Zichermann and Linder 2010). Current technologies, together with the widespread and massive use of social media and mobile devices, can be identified as joining causes which are facilitating the diffusion and adoption of gamification techniques in so many and different contexts (Seaborn and Fels 2015).

The first successful example of gamified service has been Foursquare. Starting from such an experience, other several gamified applications were born, exploiting game elements together with interactive design and digital marketing issues (Zichermann and Linder 2010). At the same time, gamification has been recognized as a key issue to support and incentive massive collaboration from and among users (McGonigal 2011).

The goal of this work is to define gamification, by summarizing game design elements which characterize it and by describing how such elements can be exploited in crowdsourcing systems, improving crowd's experience and involvement.

The remainder of the work is organized as follows. The "Gamification" section describes the introduction of the term, the game elements which characterize it, and players' motivations. The section entitled "Gamification in Crowdsourcing Systems and Social Media" presents some examples of crowdsourcing applications which benefit from the use of gamification. Finally "Conclusion" closes the paper.

Gamification

The word "gamification" has been used for the first time in 2010, when Jesse Schell gave a talk entitled "Design Outside the Box" Schell (2010): he foresaw the use of game mechanisms with the aim of increasing users' engagement in non-gaming contexts (Bouça 2012). After that, "gamification" has become a buzz and trendy word (Deterding et al. 2011), and its techniques have been applied in different contexts and applications: from education (Foster et al. 2012) to wellness and health (Cafazzo et al. 2012), from marketing (Downes-LeGuin et al. 2012) to sustainability (Liu et al. 2011), etc.

Actually, the use of game design, elements, and mechanisms in non-gaming contexts is an old topic: in human-computer interaction, the idea of exploiting enjoyable interfaces from games went back to the 1980s (Malone 1982). More recently, several works have been inspired by game design in reaching the goal of identifying principles, patterns, and elements that might provide joy of use and enhancing the motivational affordances of computer-supported collaborative work (Jung 2010), on the basis of researches on the motivational psychology of video games (Ryan and Deci 2000).

Several works propose some alternative terms for gamification (Seaborn and Fels 2015; Deterding et al. 2011), including "ludification" (Bouça 2012), "behavioral games," "serious games," and of similar concepts, such as "games with a purpose" (von Ahn 2006), "pervasive games," and "augmented reality games."

Even if the gamification concepts and techniques, as well as the psychological and sociological users' motivation, have been studied and applied in several contexts (Deterding et al. 2011), a lot of questions are still open, such as: "how many game elements does it take until a gamified system becomes a game?" (Seaborn and

Fels 2015). In this sense, the term "gamification" can also be used to describe the transformation of an existing system into a game: gaming elements and concepts could be inserted into a system (enhancing existing elements) or the system could be converted into a game (Mekler et al. 2013).

Game Design Elements

Seaborn and Fels (2015) and Mekler et al. (2013) have analyzed several works, identifying main game elements which are exploited in gamified systems. A list of such elements follows:

- *Points* (*experience points*, *score*): they are numerical units which indicate users' progress.
- *Badges* (*trophies*): they are visual icons which indicate users' achievements.
- *Leaderboards* (*rankings*, *scoreboards*): they display ranks for comparison among users.
- *Progression* (*leveling*, *level up*): they are milestones which indicate users' progress.
- *Status* (*title*, *ranks*): they are textual names which indicate users' progress.
- *Levels* (*stages*, *areas*, *worlds*): they indicate increasingly difficult environments.
- *Rewards* (*incentives*, *prizes*, *gifts*): they indicate tangible, desirable items the users aim to obtain.
- *Roles* (*class*, *character*): they indicate role-playing elements of character.

Game design issues in systems applying gamification have been analyzed by Seaborn and Fels (2015) and Deterding et al. (2011) and can be listed as follows:

- *Game interface design patterns*: they can be identified with common, successful interaction design components and design solutions for a known problem in a context, including prototypical implementations. Some examples of game elements based on this issue are badges, leaderboards, and levels.
- *Game design patterns and mechanisms*: they are commonly derived from traditional game design, as, for example, time constraints, limited resources, and turns.
- *Game design principles and heuristics*: they can be identified with evaluative guidelines to approach a design problem or analyze a given design solution. Some examples are enduring play, clear goals, and varieties of game styles.
- *Game models*: they can be understood as conceptual models of the components of games or game experiences. Some examples are challenges, fantasy, curiosity, game design atoms, and core elements of the gaming experience.

Players' Motivations

Game design mechanics and dynamics are mainly based on users' motivations (Blohm and Leimeister 2013), which can be driven by intrinsic and/or extrinsic motivators. These psychological terms describe different ways in which people can "be moved to do something" (Ryan and Deci 2000). On the one hand, intrinsic motivation is defined as "the doing of an activity for its inherent satisfactions rather than for some separable consequence." When intrinsically motivated, a person acts for the fun or challenge entailed rather than because of external prods, pressures, or rewards (Blohm and Leimeister 2013). On the other hand, extrinsic motivation "is a construct that pertains whenever an activity is done in order to attain some separable outcome," just like a reward (Mekler et al. 2013). In this sense, gamification is based on the extrinsic motivation, which can be effective in changing behavior and creating loyalty in users (Bouça 2012).

In Blohm and Leimeister (2013), motivations are associated to game design mechanics and dynamics as follows:

- *Intellectual curiosity*: it has been associated with documentation of behavior (as game mechanics) and exploration (as game dynamics).
- *Achievement*: it has been associated with scoring systems, badges, and trophies (as game mechanics) and collection (as game dynamics).
- *Social recognition*: it has been associated with rankings, levels, reputations (as game mechanics), and competition and acquisition of status (as game dynamics).

- *Social exchange*: it has been associated with group tasks (as game mechanics) and collaboration (as game dynamics).
- *Cognitive stimulation*: it has been associated with time pressure, tasks, and quests (as game mechanics) and challenge (as game dynamics).
- *Self-determination*: it has been associated with avatars, virtual worlds, and virtual trade (as game mechanics) and development and organization (as game dynamics).

Gamification in Crowdsourcing Systems and Social Media

Nowadays, crowdsourcing is commonly adopted by several systems, with the aim of performing distributed and collaborative tasks (Estellés-Arolas and González-Ladrón-de-Guevara 2012). Some of these projects exploit human abilities when they can overcome and solve problems impossible to be completed by a computer, such as the annotation and/or tagging of images, videos, or web and social media content. As an example, the reCAPTCHA project (von Ahn et al. 2008) takes advantage of the crowd in solving CAPTCHAs to help to digitalize books and newspaper, while the Dotsub platform (http://dotsub.com) aims to collect video captions from the crowd.

Several crowdsourcing systems apply different gamification techniques with different aims and contexts. Some examples are presented in the following.

Gamification in Multimedia Tagging and Captioning Systems

A famous project based on random web image labeling is the ESP game (von Ahn and Dabbish 2004), an online two-player game with the goal of guessing what label the other player would give to the displayed image. This is one of the first examples of game with a purpose (GWAP) performing useful tasks by means of crowdsourcing. The gaming elements introduced are points, time constraints, comparison between the players (as leaderboard), and intermediate results (as progress). ESP game evaluations show that the gamification techniques reached the main goals of engaging users and increasing the user-generated content.

Labeling images is the aim of Mekler et al. (2013) too. The authors applied different gamification strategies to an already existing image tagging platform and involved participants, asking them to enter labels related to a shown image. The authors developed different versions of the same system, as many as the game elements they applied (points, leaderboard, and levels). Then, they have compared such versions together with a non-gamified one. The tests show that those gamification elements concur in enhancing users' performance, promoting a specific user's behavior.

People with special needs are taken into account by Kacorri et al. (2014), where the authors proposed the adoption of game elements in crowdsourced video captioning, so as to increase video accessibility for deaf and hard-of-hearing users, providing benefits also to second-language learners. The authors exploited an already existing collaborative caption editing system, which has been equipped with points and time constraints. A pilot experiment showed the feasibility and the effectiveness of the proposed gamification.

Gamification in Learning Language and Translation Systems

A very famous project which exploits crowdsourcing and gamification in the same translation system is Duolingo (https://www.duolingo.com/). Duolingo is a free language-learning and crowdsourced text translation platform. Engaged users learn a language, progressing through the lessons, and help to translate any web content (including images, video, tweets, and so on) into their native language, at the same time. Game elements are applied in the learning part of Duolingo: from points to time constraints and from levels to leaderboard.

The aim of AlRouqi and Al-Khalifa (2014) is the translation (also in the image-to-text form) of Arabic documents, so as to make them more accessible, even to those users with low vision.

The authors proposed a mobile crowdsourcing system, where they have applied gamification mechanisms (in particular points, leaderboard, and time constraints).

Liu et al. (2011) have designed and developed UbiAsk, a mobile crowdsourcing application for image-to-text translation. UbiAsk exploits points, status, badges, and leaderboard so as to encourage participants to tag and translate images provided by foreign travelers, so as to support their language comprehension. Experiments were conducted and confirm an increasing involvement of the participants when gamification strategies are applied.

Gamification in Location-Based Systems

Foursquare (http://www.foursquare.com/) represents the most popular example of gamification in crowdsourcing systems and social media (Bouça 2012). It is a location-based mobile app, which lets the users provide information about their location, about suggestions related to a certain location, and so on. It applies most of the common game elements typically involved in gamified apps: points, badges, leaderboards, and incentives (Zichermann and Cunningham 2011). Points are used to track game status and feedback, badges to set goals, leaderboards to add a competitive layer, and incentives represent the reward.

Other well-known examples are Waze and Swarm. Waze is a GPS-based geographical navigation application for smartphones with GPS support, which provides information and user-generated content about travel times and route details, downloading location-dependent information over mobile networks. Waze uses gamification (points) to engage users and encourage them to provide more information. Waze also offers points for traffic or road hazard reports, which can be used to change the users' avatar and to increase users' status in the community (https://www.waze.com/).

Swarm is a mobile app that lets users share their locations within their social network (https://www.swarmapp.com/). It is a spin-off of the older Foursquare, which supports users in checking in to a given location, as well as making future plans with friends and seeing who is nearby. Swarm exploits badges, points, and competition against all other users of the service to improve their level, becoming the "mayor" of a location.

Gamification has also been applied in location-based systems with specific purposes, such as supporting citizens with special needs in urban environments (Palazzi et al. 2011; Prandi et al. 2015; Salomoni et al. 2015). While the former exploits points and rewards, in the latter the game scope is totally different from collecting data, but data gathering permits to gain weapons which can be used in zombie hunting.

Conclusion

In this work we have defined the term "gamification," which identifies a still emerging but significant trend related to serious games and games with a purpose. We have identified main game design elements and users' motivations at basis of gamification. Moreover, we have described how gamification techniques can be applied in crowdsourcing systems, by presenting some examples where gamification reaches the goals of engaging users, involving them in providing user-generated content. In many contexts and systems, gamification is still an ongoing process.

Cross-References

- Augmented Reality
- Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay

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Gamification of Cooking

▶ On Computer Games About Cooking

Gamification of Modern Society: Digital Media's Influence on Current Social Practices

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Synonyms

Game mechanics; Gamified experiences

Definition

Gamification is the implementation of game mechanics for use in areas typically not associated with gaming (Kadison 2015). Gamification engages users and solves problems through use of game-thinking and game mechanics processes (Zichermann and Cunningham 2011). The difference between gamification and game play (i.e., physical fitness games versus candy clearing games) is that with gamification the creator is looking to solve a real-world problem (Kim 2015a). For example, applications such as wrist pedometers encourage individuals to get in shape through gamification and works to solve the real-world problem of weight gain. Applications aimed at learning a second language encourage individuals to become bilingual and solves the real-world problem of limited bilingual speakers and services available.

Introduction

In today's society, gaming culture and use of modern digital media devices has influenced the casual user by assisting in solving real-world problems through the mode of fun and gamification (Kim 2015a). The scope of gamification has been implemented in businesses from health and fitness industries, to retail marketing, and to the education and learning industries. In 2013, the gamification market was worth an estimated $421.3 million and is expected to grow to $5.502 billion by 2018 (Gamification Market Worth nd). This would give the industry a compound annual growth rate of 67.1 %! It would appear the use of gamification is lucrative and will only continue to grow based on the projected increase in worth.

Over recent years, society has witnessed the ever-growing influence and acceptance of technology and digital game concepts being incorporated in our day-to-day lives. The use of these "gamification concepts" include various psychological approaches regarding the use of technology to aid in evoking, motivating, influencing behavior and even changing the habits of the user (Kim 2015a).

Using today's technology, users have begun to incorporate game-like point-based methods to affect everything from shopping habits, education patterns, and even their physical and mental personal health. With the ever-growing availability of technologies such as wrist pedometers and smart watches, to the language learning applications, we as a society are seemingly thriving more and more on technology and gamification to influence our everyday lives.

What drives us as a society to explore and accept these "seemingly empty" point-based applications that influence our actions so strongly? What internal rewards do we receive? What constructs are affected by us using gamification in our everyday life? This paper will explore the gamified experience, current research, knowing the player, and implications of gamification on society.

Where Do We Find Gamified Experiences?

Though instituted in the early 2000s, the popularity of gamification has seen a relatively rapid rise

since 2013 (Gamification Market Worth nd). Its initial development and implementation was intended to leverage crowds, process data, and help influence consumer behavior through the implementation of game mechanics (8 Reasons 2014). So where do we find the use of gamification? Many companies over the past few years have implemented the use of gamification to leverage their consumer interaction. The goal of these games is to intrinsically motivate the user and offer increased satisfaction (as the user is able to obtain immediate feedback and set achievable goals), feel optimistic, (encourages self-determination and gives the user a sense of personal achievement), encourage social interaction (through social exchange), and give the user meaning (as they are working toward solving problems) (Blohm and Leimeister 2013).

Gamification is also aimed at increasing mental health. It introduces the idea that the user can be autonomous while being in control and having fun (Blohm and Leimeister 2013). These ideas are based off of the idea of the "fun theory." The fun theory asserts that fun is the easiest way to change behavior for the better (The Fun Theory nd). Gamification can also spark behavioral change. As the individual is engaging in gamification, they are getting positive emotional feedback. This can spark a change in habits or create a new, healthier habit. For example, an application that encourages mindfulness and meditation encourages individuals to increase positive coping skills and is aimed at decreasing symptoms of anxiety. One such application is advertised as a gym membership for the mind and uses game to change an individual's daily habit and routine in order to improve mental health. Consequently, there has been an increasing interest in use of games in child therapy and mental health over the past 10 years (Schaefer and Reid 2000).

Gamification has also broken through into the fitness industry. For example, Nike released an application that sparked two million individuals to burn 68 bn calories (Blohm and Leimeister 2013). There are also other popular fitness applications, which helps the individual track their exercise, sleep, and calorie intake. As the individual increases their steps they are rewarded through badges and encouraging statements. The individual can also interact with their peers and engage in competitions to track their fitness for the day.

Gamification has also impacted the educational and business field. Deloitte (a small company) developed a gamified online training program (Deloitte Leadership Academy) (Kim 2015b). Use of the gamified training program resulted in an increase in amount of time people spent on program and an increase in number of programs completed. This training also showed a 37 % increase in users returning to the site (Kim 2015b).

Colleges are also using the concept of gamification in their orientation to increase engagement. A professor at the University of Michigan went so far as to create his undergraduate class in game form. This gave students the ability to choose their own options to meet the learning goals of the class while getting feedback and being able to join "guilds" in the classroom (Kim 2015b). Bilingual applications have also increased education by creating a fun way for an individual to become bilingual. A study conducted by the City University of New York and University of South Carolina found that 34 h spent on a bilingual application is equivalent to a semester (roughly 11 weeks) of a language at university (DuoLingo 2015). This makes learning free and accessible to anyone with access to this application.

Even the retail industry has seen a rise in gamification experiences. Many credit cards now have offer point systems in which they use rewards such as, travel and consumer products, to entice the consumer to sign up for their credit card (Olenski 2014). In this way, gamification is beneficial for both the industry and the consumer. By participating in the loyalty reward programs, consumers feel that they are getting a "deal" by cashing in points for simply spending their everyday dollar (this gives them the control previously discussed). This gives the consumer multiple reasons to spend money and motivates them in the market place (8 Reasons 2014). This also benefits the credit card companies as they can partner with various retail sponsors so that point users are required to cash in their loyalty points with those vendors. This free advertising is beneficial for the

retail companies and they in turn help sponsor and support use of the specific credit card.

Research and Future Direction

In 2014, 500 Thai consumers were surveyed about the influence of gamification in their everyday lives (Zepeda 2014). The highest age of interest was between 24 and 32 year olds, and 88 % of the 500 consumers surveyed said they would choose to buy brands with a reward point system. In fact 85 % said they would pay more for the product if there was a gamified mechanic involved in the product (Zepeda 2014). With this type of interest it is no surprise that businesses are jumping at the chance to implement game mechanics into their products.

Other research show that child gamers are "letting off steam" in response to problems with friends or parents, with feeling of guilt or frustration in their gameplay (Colwell 2007). There has been an increasing interest and use of games in child therapy over the past 10 years (Schaefer and Reid 2000). Child therapists often times have to carry multiple board games and toys into therapy sessions to engage interactively with their clients. Therapists use play therapy techniques to help children gain emotional trust with them and heal through use of fantasy in which they are able to explore previous trauma or current life stressors in a safe and nonjudgmental environment (Schaefer and Reid 2000). The idea of taking preexisting games and changing the rules is not uncommon. The future of gamification will be incorporating these elements of games for noncommercial use and providing them to doctors and health care professionals in order to better diagnose and treat conditions.

Why Do We Game?

Before we understand the elements of gamification, we must first understand why people play games. The root of most game play is interaction and engagement of the player. Players are often times drawn to gaming as an escape from their world and a therapeutic release. Gaming allows player to not only engage in the game play but also become a bigger part of the games community. In turn subcommunities are formed within these gamified experiences to develop not only a player's social network, but also the player's reputation.

Gamification implements many common game mechanics into non-typical game activities. Badges or rewards, points, level upgrades, leaderboards, and challenges are just a few of the ways companies draw users into utilizing their gamified experience. Using these milestones and badges creates support as individuals use gamification to problem solve ways to accomplish the game's goal (Blohm and Leimeister 2013).

The badging effect promotes player participation by the reward of a graphic icon with any level or point upgrade in the game. By doing so, badging helps members feel more involved in their community (i.e., social support as discussed earlier). Many gamified experiences start their players off with a welcome badge just for downloading their applications. This immediately gives the player a sense of community from the get-go. In turn all badges are typically displayed on the members profile so they may compete against one another.

Point systems are used to help obtain badges. When an application needs to provide the player with a measurement of their accomplishments, they typically are rewarded points. This is typically done by the developers assigning points to common actions such as checking in, miles run, and even comments made on a particular forum. For example, Texas Instruments gives points to their employees who ask and answer questions on their internal forum. The points are, in turn, used to boost an employee's reputation and eventually lead to social and economical promotion within the company.

The driving force behind all gamified experiences is, as mentioned, giving the player a sense of community, autonomy, and control (Blohm and Leimeister 2013). Players are influenced by mechanics like points and badges but other elements need to occur within the game in order to retain players for increased periods of time of the

game experience. Instant feedback and clear goals are two of the most important elements of keeping the user involved within the application. Gamification should be composed of a variety challenging but achievable tasks with compelling outcomes. By retaining players within the gamified applications, users will not only stay involved in the social community created but this will also influence them to bring new players into the social network.

Knowing Your Player

Bartle describes four common types of gamers: killers, socialites, achievers, and explorers (Bartle 2008). Killers focus on winning and direct competition, while socialites focus on developing a network of friends and contacts. Achievers focus on attaining status and achieving goals, while explorers focus on discovering the unknown. Knowing these four types can help industries appeal to various players.

Businesses that wish to bring a gamification experience into their consumer relationship need to be aware of these player types. While focusing on one player type might seem like the most logical step in developing a gamified experience, an experience with a combination of the four player types might be the most impactful way in development and implementation. In doing so, businesses will be able to customize their games and gaming experience to their consumers in very specific ways. It is important that the developing business understand the competitive spectrum of the player when inciting players to interact with their gamified experience. Players do not have to fall into one of Bartle's singular player types but, put simply, their competitiveness must be measured. Caring, collaborative, cordial, competitive, and combative are a few of the player motivation scales (Bartle 2008).

Conclusion and Discussion

In conclusion, the idea of sitting in front of the board game, television with a console system, or an arcade machine to play game has begun to become a thing of the past. The elements of gaming have gone beyond entertainment and found their way into the consumer world. The gamification of modern society really begins to blur the lines of what is considered a game. Most aspects of everyday consumer life are influenced by elements found in games, such as, competition, reputation, and our social network.

What is the future of gamified experiences? As mentioned, the gamified experience has gone beyond the arcade and entered our everyday lives. When does the term "game" become obsolete in our society? Will there ever be a time a place where these elements are simply integrated to all aspects of our everyday routines? In addition, will there be other uses for gamification beyond entertainment and consumerism?

The future of gamification, in my opinion, is to help invoke social change. Current research shows positive mental health benefits in playing commercial-based interactive games. Could these same concepts be spun into gamified experiences to better serve treatment of patients in healthcare? With the increase in interest and use of games in mental health, therapists are able to incorporate gamification into their session to incorporate play therapy techniques to promote healing and behavioral changes. Future implications could include gamification incorporating these elements of games for noncommercial use and providing them to doctors and health care professionals in order to better diagnose and treat conditions. As bilingual applications have done with their applications, the use of gamified experiences within the education industry is just as important. Providing instant, accessible, and efficient motivators of learning will indeed shape the industry for years to come. Physical well being is also increased with use of gamified physical fitness applications. Gamification seems to present a holistic approach as it can incorporate mind and body into its approach. Consumerism will always be a part of this industry and practice, but the more accessible we can make these applications the more beneficial they can become to society.

Cross-References

▶ Gamification in Crowdsourcing Applications

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Gamification: Ludification

▶ Gamification in Crowdsourcing Applications

Gamified Cooking

▶ On Computer Games About Cooking

Gamified Experiences

▶ Gamification of Modern Society: Digital Media's Influence on Current Social Practices

Gaming

▶ Virtual Reality Game Engines

Gaming as a Service (GaaS)

▶ Cloud for Gaming

Gaming Control Using BCI

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Synonyms

Brain control interface; Game control; Human-computer interaction

Definition

A Brain-Computer Interface (BCI) is a device that can obtain all operations of the brain that has become a promising technology in human-computer interaction (HCI). HCI has a clear

primacy in the world of gaming as gamers are one of the largest HCI app subscribers. The human thoughts are transmuted by the brain over brain signals and expressed as an attitude. This process is mainly carried out over brain signals, which are the key component in the electroencephalogram (EEG).

Introduction

The gaming system is the main research trend of HCI, which comes from the widest implementation of games within various fields in this domain. The BCI technique becomes a leading control for the new virtual systems as it provides a direct pathway of communication between the external environment and the users' brains. In 2017 and 2014, Ismahafezi et al. (2017) and Abuhashish et al. (2014) agreed that EEG signals research is a current approach in BCI due to its usability in the HCI field. Therefore, the rapid revolution growth of HCI in the field of gaming using BCI considered a future pursuit. A cheap and easy way to use the BCI device has been developed by Emotiv, which is called EPOC. This device is used without the intervention of tangible senses including hands to control the game; it depends on brain activity that expresses the game player moving control, facial expressions, and emotions. Therefore, there is no need to use sticks, buttons, motion sensors or gyroscopes as in traditional game controllers. To perform as a game controller, the obtained EEG signals need to be interpreted into meaningful instructions in a course that enables easy game playing.

Computer games always have a large market, according to Global Entertainment and Media. BCI Games could be a very interesting field in the near future to adapt this innovation. Allison et al. (2007) stated that the gamer is listed as the first BCI user, given that BCIs give a useful and reliable feature. Van Erp et al. (2012) have also predicted that games and entertainment will be the first mainstream use for unmedical BCIs. The fBNCI project reported that BCI is the second of the top five most successful BCI support software frameworks (Future BNCI 2014). The number of potential users of BCI applications is largest (Ahn et al. 2014), and the financial viability of BCI technologies is high too (Van Erp et al. 2012). Furthermore, appropriate BCI devices with sensors that do not need gel are launched on the market (Ahn et al. 2014). Taking into account these advantages perceptions of BCI-based games and the production for the public of EEG instruments, it does seem apparent that the first successful use of the platform would soon be BCI-based games, whereas BCI's medical technology is often presented as a groundbreaking technological software.

This means that playing instructions should be operated at the exact real time with less delay and never changing user state. The BCI EPOC device should be calibrated to control the game in a proper way. Moreover, there are not many games designed and developed to be used with a BCI device. A BCI game needs to be designed and developed in an accurate way to utilize BCI device capabilities completely.

Related Work

Virtual technologies can be strong BCI advocates and video games. Researchers showed that BCIs provide the correct interface instruments for both video games (Ismahafezi et al. 2018) and VR (Abuhashish et al. 2015a; Abuhashish 2020) applications. On the other side, the researchers widely agreed that VR is a promising and productive platform to create more research and improve BCI systems. The process of interaction with the virtual environment can be subdivided into specific tasks (Wang et al. 2011), for instance, to select and manipulate or change viewport of any objects in the virtual environment.

The latest BCI technologies in the virtual world will allow users to modify the position of camera within a video on the left or the right using two different brain stimuli, including left- and right-hand motor imagery (MI), or two visual-evoked lasting potentials (SSVEPs). Also, MI-based BCIs were useful for controlling the

direction of a virtual car (Wang et al. 2011), navigating a virtual bar (Ismahafezi et al. 2018) or moving along a virtual environment or via a virtual plane (Abuhashish et al. 2015a; Abuhashish 2020).

Many medical and research games were designed to study the effectiveness of brain-controlled interfaces. At The University College Dublin and MediaLabEurope, the researchers developed a BCI-based video game called MindBalance (Wang et al. 2011) for engaging with virtual environments. In response to phase-reversing checkerboard patterns, the formed BCI uses the SSVEP created. This SSVEP significantly simplifies the techniques of signal processing so that clients have little or no instruction (Yisi Liu et al. 2010; Wang et al. 2011).

Neurofeedback studies have been carried out based on existing video games with different game consoles, such as Nintendo and PlayStation (e.g., Spyro the Dragon). In second life (Pineda 2003), and the MindBalance simulation (Lalor et al. 2005), movement visualization-testing techniques have been used. In Second Life, First-Person Shooter game (Pineda 2003), MindBalance game (Lalor et al. 2005), and Pacman (Wang et al. 2011), the researchers used motor imagery applications. Low-cost EEG-developers have created neurofeedback's-modulated, exciting, and difficult games (e.g., Neurosky, Nintendo, Microsoft, and Arena by Emotiv) that are frequent-play-motivating for the user.

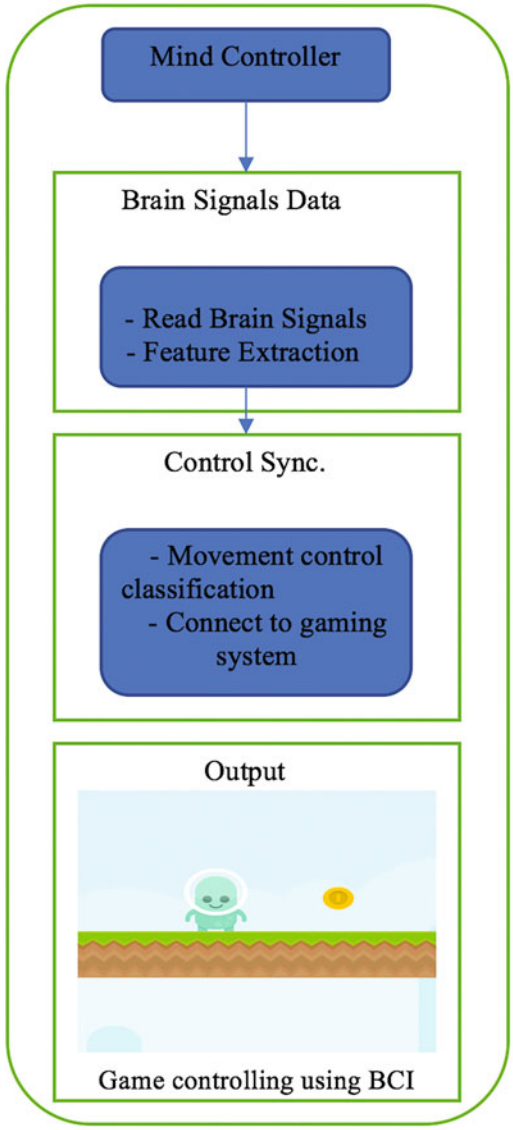
With regard to the literature study (Abuhashish et al. 2015b), it is believed that the developed EEG-based ADAPTIVE Game will sustain the user involved in the game as the complexity level is changed by cognitive assessments of the participant. The results of the BCI proved high in avoiding disruptive visual stimulation and were relatively consistent over six topics in the visually rich environment of the match, with 41 of 48 players being successfully achieved. Eighty-nine percent of respondents had acceptable precision in real time. Many subjects also increased progress in the completion of the game. It indicates that a more focused attitude and experience to the fixation of information contributes to a better visual reaction.

Problem Statement

The approach of controlling games using BCI has been eagerly awaited by game players since the game players did not feel that they reflect the reality of their situation while playing games using the traditional way. Furthermore, occasionally, some issues like slow response time in traditional game controllers appear, thus causing disappointment. In addition, spending a long period playing with traditional game controllers causes issues regarding health. It was believed that using a brain-computer interface as a new game controller may solve the issues as mentioned earlier. Although this research area appeared relatively recently, it can grant us a glimpse of the evolution of game controllers in the future. Nevertheless, the existing BCI technology like EPOC device does not focus on the game controller's application. Furthermore, until today, there are not many games that are designed using BCI technology. For the mentioned reasons, BCI-based games need to be designed to make the best use of brain computer-interface technology by providing a better level of immersion to look and feel real. Many approaches are used in the five main phases that are stated in Fig. 1.

Significance of the Study

Virtual reality has been utilized in several areas including gaming (Abuhashish et al. 2015a). In all previous studies, the main focus was on the world of virtual reality in many fields. Moreover, controlling a game using users' brain signals has a strong effect on enhancing the interactivity due to the expanding range of utilizing brain signals to control the virtual environment, which still needs more definition with efforts. Therefore, this scenario depicts a significant research area to be investigated. The proposed approach attempts to



Gaming Control Using BCI, Fig. 1 Used approach

combine users' brains with the gaming system using BCI (Abuhashish et al. 2015b).

Brain Signal Classification

In order to produce an accurate classified controlling system to be ready for mapping and synchronizing with the gaming system, the acquired mental activity obtained by brain signals must be subjected to preprocess by means of features recognition. Therefore, there are lots of BCI-based controlling recognition methods that have been proposed and implemented within the last few years. All of these works involved the extraction of electroencephalogram (EEG) signals from brain activities (Fig. 2). Then, the signals are classified into several parameters suitable for controlling the game accurately.

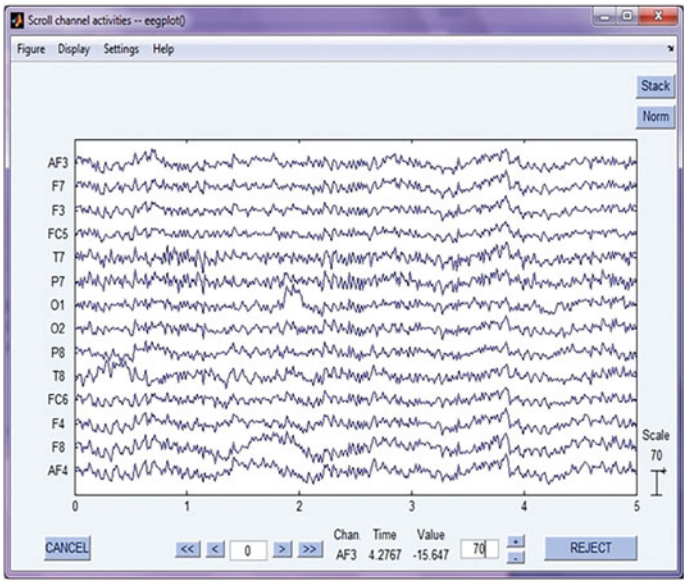
HIGUCHI Feature Extraction

In 2010 and 2011, Yisi Liu et al. (2010) and Wang et al. (2011) introduced fractal dimension FD based on the algorithm of quantification of primary controllers and described its implementation as feedback in virtual environments. Players' controller is recognized and visualized in real time on their virtual game by adding a parameter called "controlling dimension" to human-computer interfaces.

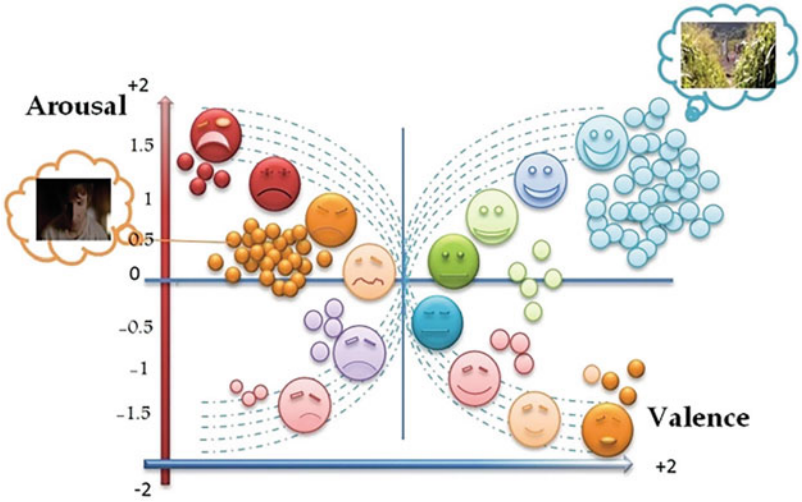
In this study, Higuchi algorithm (Higuchi 1988), based on fractal dimension computation values, was used. Higuchi algorithm provided improved accuracy, unlike other fractal dimension algorithms as stated in the study of (Russell 1980; Yisi Liu et al. 2010). At this point, the Higuchi algorithm was evaluated using Brownian and Weierstrass functions, where theoretical FD values are known.

To summarize, when comparing the HIGUCHI fractal dimension calculated values with the Mean, they are identified as a form of control state by correlating them with the representation of control in the arousal-valence model. Any change in the result of HIGUCHI fractal dimension is mapped alongside the axis of arousal (Fig. 3), where the high value of HIGUCHI fractal dimension result is positively related to high arousal level.

The Higuchi algorithm determines the fractal dimension (FD) quality of regression details. Wang et al. (2011) say that the Higuchi algorithm (Higuchi 1988) can be relied on in order to calculate high accuracy in contrast to other fractal dimensional algorithms. A research assessment on Brownian and Weiestrass methods (Wang et al. 2011) has verified the utility of Higuchi algorithm. However, the high value of the findings of Higuchi Fractal Dimension (HFD) is likely to generate an improved anticipation. Eqs. 1 and



Gaming Control Using BCI, Fig. 2 Controlling brain signals



Gaming Control Using BCI, Fig. 3 Valence_arousal model for movement control recognition

2 have illustrated the main parameters used as the main parameters in HFD algorithm.

Given a time series of one dimension *x(1),x(2),* ⋯*,x(n)s,* the HFD calculation algorithm can be defined as below:

Step 1: *Select one value of k*

Step 2: *Construct the subseries* $X^m{}_k$ *from the time series as following*

$$X^m{}_k = x(m), x(m+k), \cdots, x(m+[(n-m)/k] \times k) \quad (1)$$

where $m = 1,2,\cdots,k$ and [ ] denotes Gaussian notation that rounds a number in the square brackets to its maximum integer equal to or less than themselves, m the initial time, and k the time interval. For example, when $k = 3$ and $n = 100$ having three subseries as follows:

$$X^1{}_3 : x(1), x(4), x(7), \cdots, x(100)$$

$$X^2{}_3 : x(2), x(5), x(8), \cdots, x(98)$$

$$X^3{}_3 : x(3), x(6), x(9), \cdots, x(99)$$

Then each subseries length $X^m{}_k$ is calculated. Length $L_m\,(k)$ of $X^m{}_k$ is equal to

$$\frac{\left\{\left(\sum_{i=1}^{int\left(\frac{N-m}{k}\right)} |x[m+ik] - x[m+(i-1)\times k]|\right)[(N-1) \div (int((N-m) \div k) \times k)]\right\}}{k} \tag{2}$$

Step 3: *Calculate the average length L(k) of all Lm(k)*

Step 4: *Repeat step 1–3 for several values of k*

Step 5: *Slope of the curve of ln(L(k))* versus *ln(k) is approximated. FD value is the slope multiplied by −1.*

In a previous study of the algorithm Higuchi, this algorithm demands that the principal EEG signal be divided into many signals to boost the readings of human motor imagery and to create new parameters. This improved outcome results in higher reliability and allows further motor imagery to be explored. For these purposes, the fractal dimension of Higuchi is ideal for most human motor imagery.

Control Classification Based on the Circumplex Model

It has been considered that each controller relates to an approximation interval within the arousal-valence model based on the Circumplex model (Davidson et al. 1990) as in Fig. 4. To analyze the EEG signals in terms of mind controller, two frequency bands are usually considered: alpha (8–13 Hz) and beta (13–30 Hz). It has been shown that the power of these sub-bands carries useful information related to controller states. In 1988, Higuchi (1988) showed that the left hemisphere controls the right movement, which causes a minimal amount of alpha-band power, whereas the right hemisphere causes minimal alpha power and, in turn, controls the left movement. Moreover, Higuchi (1988) found that the peak in the frequencies of alpha-band power increases when the human is subjected to movement control order.

Control Dataset

Since the recognition of control movements is about a new domain, a dataset of EEG signals benchmark needs to be set up that could be used for further EEG-based control recognition studies. In this study, by depending on the emotive brain controller device, the dataset was collected after applying a specific stimulus scenario in the course of analyzed movement control to come across the inner movement control imaginary patterns (Fig. 4).

Gaming Control Using BCI, Fig. 4 Collecting movement imaginary brain EEG data signals

In addition, the research strongly depended on building questionnaires that can furnish us with the right subject regarding stimuli. In the subject matter, an individually random person was examined by giving certain stimuli to acquire imaginary movement control such as go forward, go left, go right, and jump.

Control Mapping

After the classification process, the real human imaginary movement control to the Circumplex model was mapped. This process involved all real imaginary movement control that represents all categories of the control stage.

Game Animation

External effects and user interaction control the game. Controlling a game based on movement control imaginary is considered one of the promising research domains in the animation field (Abuhashish et al. 2015b) since there is a lack of interaction between game players and games in the course of mind controller (Abuhashish et al. 2015b; Ismahafezi et al. 2018).

Some ideas and concepts have been explored and applied to bring more significant game controllers and devices in the last few years (Wang et al. 2011). Furthermore, in the majority of prior research, a wide range of devices has been employed to create immersive games and virtual reality experiences associated with control systems, aiming to achieve high levels of quality. The devices mentioned in the introduction are considered popular even without players and do not reflect user sentiments.

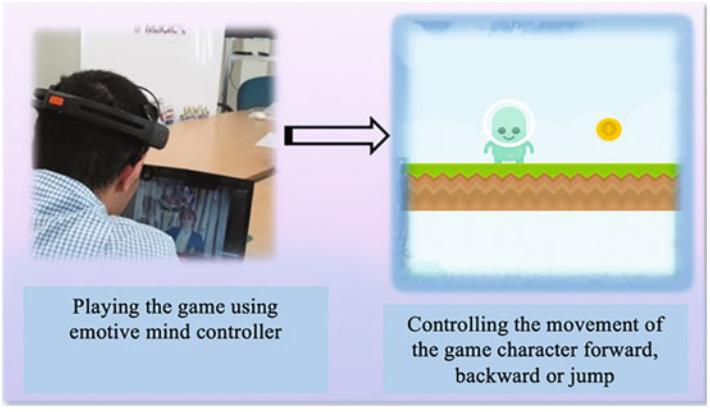
Game Controller

Real human control generated from mental activities means that the main controller of any human movement is the human mind based on certain reactions. In this study, the focus was given on human movement control stimulated by their reactions. Each movement control has an approximation degree of angle that represents the changing direction of the controlling process that expresses the imaginary movement control such as go forward, go left, go right, and jump (Fig. 5).

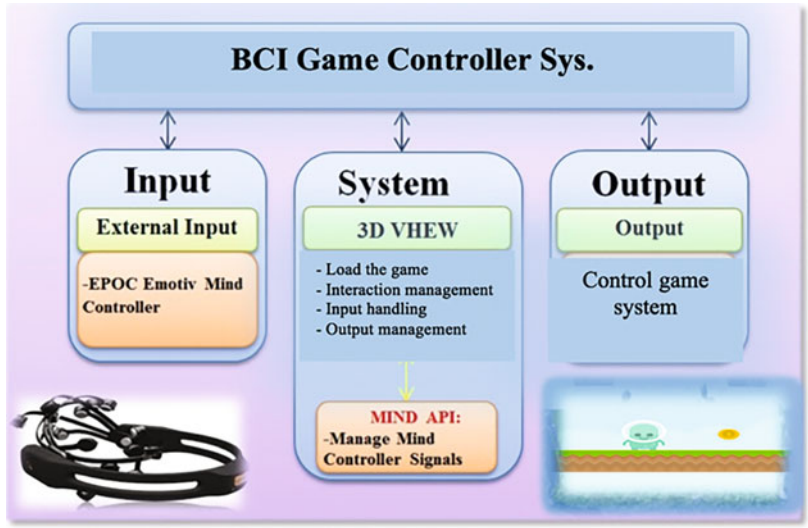
Behavior Controlling

Mental role control works by its action/reaction. Real human behavior and characteristics simulation in the gaming system has been growing in the field of computer graphics and multimedia. However, there are many scientific studies regarding real human behavior and characteristics that involve their recognition with their application (Ismahafezi et al. 2018).

Based on previous methods, this research come up with parameters to control the action/reaction of the gaming system in terms of imaginary movement control in which each is represented by a particular parameter to come up with its related behavior. By using the mind controller, the mental activities can be sync and control. In this study, one of the famous low-cost devices for the mind


Playing the game using emotive mind controller
Controlling the movement of the game character forward, backward or jump

Gaming Control Using BCI, Fig. 5 Go forward transition



Gaming Control Using BCI, Fig. 6 Operational framework for game control using BCI

controller, namely, emotive, was used, which consists of several sensors.

In this proposed framework (Fig. 6), the walking movement was represented based on game players' action/reaction. For instance, if the player wants to move forward, his imaginary movement will be mapped based on the mapping method and will be synchronized with the gaming system.

Conclusion

The utilization of the brain interface can provide strong credibility and impression to the users in any field. In this entry, an innovative framework has been studied to show how to synchronize and control the gaming system based on imaginary movement recognition from EEG signals using BCI. Higuchi FD algorithm with a gaming system was implemented since it can provide real-time analysis and sufficient accuracy. The study reveals that BCI can be used in many fields, including augmented reality, virtual reality, virtual environments, and games.

Cross-References

- Augmented Reality Entertainment: Taking Gaming Out of the Box
- Character Animation Scripting Environment
- Constructing Game Agents Through Simulated Evolution
- Game Design and Emotions: Analysis Models
- Game Development Leadership Tips
- Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay
- Redesigning Games for New Interfaces and Platforms
- Videogame Engagement: Psychological Frameworks

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Gaming Controller

▶ Query-by-Gaming

Gaming Infrastructures

▶ Online Gaming Architectures

Ganking

▶ Griefing in MMORPGs

Gap

▶ Academic and Video Game Industry "Divide"

Gardenscapes and Homescapes, Casual Mobile Games

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Synonyms

Casual game; Mobile game; Puzzle game

Definitions

Casual game:	A game that is designed to be played occasionally for a relatively short period of time without losing points or competitive advantages.
Puzzle game:	A game that requires solving puzzles in order to advance in the game.
Mobile game:	A game that runs on mobile phones.

Introduction

Gardenscapes: New Acres and Homescapes are puzzle matching mobile games created by Playrix. Gardenscapes came out in 2016, and Homescapes was released a year later in 2017. They became extremely popular with over 1 billion downloads (Chapple 2020). Being casual games, they both require very little skill and are easily accessible on smartphones as well as Facebook.

Gameplay

The main story in Gardenscapes and Homescapes follows Austin the butler as he is renovating either his family garden in Gardenscapes or his family mansion in Homescapes. The player names themselves and picks an icon to represent themselves in the game. By completing various side challenges, they can unlock new icons to represent their new achievements. The player also receives new icons by completing renovations in specific areas. These icons can be customized to best fit each player. By solving puzzles, players earn stars that can be used to clean and renovate the property as well as to unlock new areas. Each puzzle board has a goal that can be completed by matching three collected pieces or removing bubbles/bushes.

Figure 1 shows a puzzle board which is the main form of gameplay in both Gardenscapes and Homescapes. This specific puzzle board has cookies which can be broken by making matches next to them. The side panel shows that there are 15 moves, meaning that a player must collect the required items in 15 moves or less. It also shows what is required for this puzzle board: donuts and boosters. For example, the player must make the donuts drop to the bottom of the board. Players can use boosters bought before the board starts to assist them in puzzle solving.

Although the specific mechanics and objectives of Gardenscapes may vary across different versions, here is the basic gameplay loop in Gardenscapes:

1. Match three or more same objects to clear them and earn points.

Gardenscapes and Homescapes, Casual Mobile Games, Fig. 1 A puzzle board in Homescapes

2. Complete tasks assigned by the characters to progress in the game and earn points.
3. Use points to buy and place items in the garden to decorate it.
4. Discover hidden secrets and interact with characters to expand the garden further.
5. Repeat the process to complete the game and restore the garden to its former glory.

Similarly, Homescapes offers varying mechanics and objectives in different versions, but here is the gameplay loop in Homescapes:

1. Match three or more same objects to clear them and earn points.
2. Complete tasks assigned by the characters to progress in the game and earn points.
3. Use points to buy and place items in the house to decorate it.
4. Discover hidden secrets and interact with characters to expand the house.
5. Repeat the process to complete the game and renovate the house to your desired design.

Since the puzzle games are mostly luck based, there is very little skill required to win the games; it is out of the player's control where the extra pieces fall. Players have to think on the fly and adapt quickly to sudden changes. With that being said, the longer a player plays the game the better they will get at recognizing moves that will increase their chances of winning. By teaming up with friends and other players, they can help each other out by tips for the levels or gifting each other extra lives.

In-App Purchases

Although there are in-game coins that give players additional moves or lives, the games offer both free and payable prizes. For this specific microtransaction, players can pay $4.99 for a golden ticket to unlock many rewards that the player can obtain by playing the game and collecting specific pieces for that golden ticket event. There are other microtransactions such as spending real money to buy in-game coins that can be used to give a player additional moves as well as additional lives.

Reception

While the games had seen much popularity with a large number of downloads, they ended up getting a rather negative reception when they created ads that did not truly represent what the games were about. The advertisements for the two games would show game footage that was nothing like the actual gameplay. Many players first downloaded the games expecting a very different experience than what the games provided. There had been talk of banning the ads as many people accused the game publisher of false advertising (BBC 2020).

Conclusion

Mobile games are a great way for anyone to get into playing video games. Gardenscapes and Homescapes are examples of easy-to-play casual games because they are easy to get into and they require little to no skill to play. Gardenscapes and Homescapes' main gameplay loop appeals toward casual gamers (Hörgstetter 2020). With each level, a player earns stars that can be used to renovate different areas. Players feel rewarded by completing levels as well as being able to complete renovations on a mansion or garden.

Cross-References

▶ Animal Crossing: A Causal Game

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Gatchas

► Loot Boxes: Gambling-Like Mechanics in Video Games

Gaze Prioritized Graphics

► Eye Tracking in Virtual Reality

Gaze Tracking

► Eye Tracking in Virtual Reality

Gaze-Contingent Displays

► Eye Tracking in Virtual Reality

Generative Music

► Adaptive Music

Genetic Algorithm

► Classical Learning Method in Digital Games

Genetic Algorithm (GA)-Based NPC Making

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Synonyms

Artificial intelligence; *GA* genetic algorithm; *NPC* non-playable characters; RPG role-playing game

Definition

Using genetic algorithm for creating non-playable characters is the process of creating similar-looking characters from a wide variety of parent characters. After the production of subsequent populations, the characters that exhibit the best traits are chosen as the final selection.

Introduction

Non-playable characters have always been a special part of video games. Their appearance is more pronounced in role-playing games like the Elder Scrolls® series and the Fallout® series or in the open-world games like the Grand Theft Auto® series or the Assassins Creed® series. The presence of these characters is either to provide the player with objectives to complete or give a sense of a living world with people going on about their business. The variety of these characters is however lacking which takes the player away from the illusion of a believable world. This lack of variety is attributed to the amount of man-hours required to craft an individual character. With a tight budget, the number of these individuals remains

small; hence, the same characters are repeated throughout the game.

In this article, the utility of using genetic algorithm for creating non-playable characters in games will be discussed. The previous approaches regarding the use of genetic algorithm for creating characters will be explained first, and then the usage of this algorithm in modern games will be analyzed. Finally the advantages of this technique will be explained as opposed to the normally used method of character creation.

Usage of GA

GA has been used in many research applications and character creation has not been any different. Improving AI has been a major concern as GA was used to improve the bot behavior in Unreal Tournament 2004 (Bullen and Katchabaw 2008). It has also been used to design decision trees to be used as bot's AI in the game Planet Wars (Fernández-Ares et al.).

GA has been used for defining the mental attributes of an NPC (Khan and Okada 2013). The mental attributes of characters were composed of actions which were distributed into good and bad actions. The good actions were allotted low numerical values, while the bad actions were given high numerical values. The concept here was that if the sum of the actions was small, then the character's mental attributes contained mostly good attributes. If the sum of the actions was large, then the character mostly contained bad actions. By desiring a certain sum by the administrator, the GA tried to fit the actions such that their sum came close to the required value thus ensuring that an appropriate character is selected with a random combination of actions.

Other uses have been to create creatures which move and behave in a simulated 3D world. The morphologies of creatures and the neural systems for controlling their muscle forces were both generated automatically using genetic algorithms (Sims 1994). Genetic algorithm has been used for breeding of multiple selected parents to produce offspring via crossover and mutation functions and also for using a single parent to generate variations of a creature through mutation (Hudson 2013).

The usage of GA has been prevalent in various areas of character development from improving the AI, creating the morphology of the character from scratch to creating new breed of similar-looking creatures by using already defined parents through mutation and crossover. Video games have however not made use of this algorithm for defining the NPCs due to several reasons. One of the main reasons has been the amount of characters that can be viewed on screen at a time. Games are always trying different tips and tricks to give an illusion of huge crowds with the least amount of processing power and memory usage. The most common methodology for showing a large collection of NPCs is to use sprites as shown in Fig. 1 where several sprites are repeated to give an illusion of a large collection of people.

This technique is commonly used in modern games where the NPCs only behave as bystanders and do not play an active role in the gameplay. These can be treated as graphical artifacts used to enhance the immersion of the player when the focus is more toward the other features of the game than the player-NPC interaction. In older games like Doom®, which was a First-Person Shooter game, all the enemies were also made up of sprites as it helped to generate a large quantity of NPCs on screen even with low processing power as shown in Fig. 2.

The problem with sprites, however, is that, if we want to have variety, we will need to generate art for every individual character which will increase the art assets, causing a huge demand on memory to store those assets, thus degrading performance. As a result, the NPCs are identical copies of each other and do not exhibit randomness in appearance.

With the shift in displaying a character in 3D rather than in 2D, the possibility of defining randomly generated characters has been made possible. With games like Assassin's Creed Unity®, the current hardware is able to produce about 30,000 characters on screen if required as shown in Fig. 3.

Genetic Algorithm (GA)-Based NPC Making, Fig. 1 Crowd made up of sprites in Forza Motorsport 5®

Genetic Algorithm (GA)-Based NPC Making, Fig. 2 Multiple sprites on screen in Doom® (n.d.)

With that many characters on screen, a method is required that can cause the characters to adhere to a certain criteria and yet appear randomly. At the same time if a persistent simulation is needed, where new characters are introduced to replace the old ones, the new characters should appear similar to their older counterparts by acquiring their various traits. Something similar was achieved on a very minor scale in the game Fallout 3® where the father of the character played by the user resembled the character in facial appearance and color. If GA is used for creating NPCs, it is possible to create a vast number of random characters which adhere to a certain criteria and can even be used to make the characters appear like people in a certain demographic. This will help in personalizing the game to the people playing in that part of the world.

Genetic Algorithm (GA)-Based NPC Making, Fig. 3 Thousands of NPCs in Assassin's Creed Unity® (n.d.)

Physical Appearance

Current games, especially RPGs, provide a host of features in order to let the players create a character according to their liking. Players spend countless hours just creating their own character using the tools provided before they even start to play the actual game. Elder Scrolls V: Skyrim is one such game where the player can define his own character with a plethora of options available. An example of the different types of characters that can be created is best shown in Fig. 4.

The character creation tools are normally very intuitive and can be used to create a vast majority of characters, but creating such characters takes time, and if we want to localize the look of characters according to a certain demographic, the task becomes overly complicated. An automated system in such a scenario can play a very good role in quickly producing characters, and this is where the usage of GA can be most beneficial.

There are two ways by which a character's 3D model can be created, the first being modular character while the second being mesh deformation. Both techniques have their advantages and disadvantages. In a modular character, each individual part of the body is modeled separately. There is a skeleton of every character which keeps these modules in place. The modules are swapped to produce a random-looking character which means that every module should have a wide variety of types to choose from (Khan and Okada 2013). The disadvantage of this technique is the need to create 3D models of each body part, and this number can increase exponentially depending on how fragmented the character model is desired. The advantage however is in defining various clothing articles that can be put on the character to make it appear different.

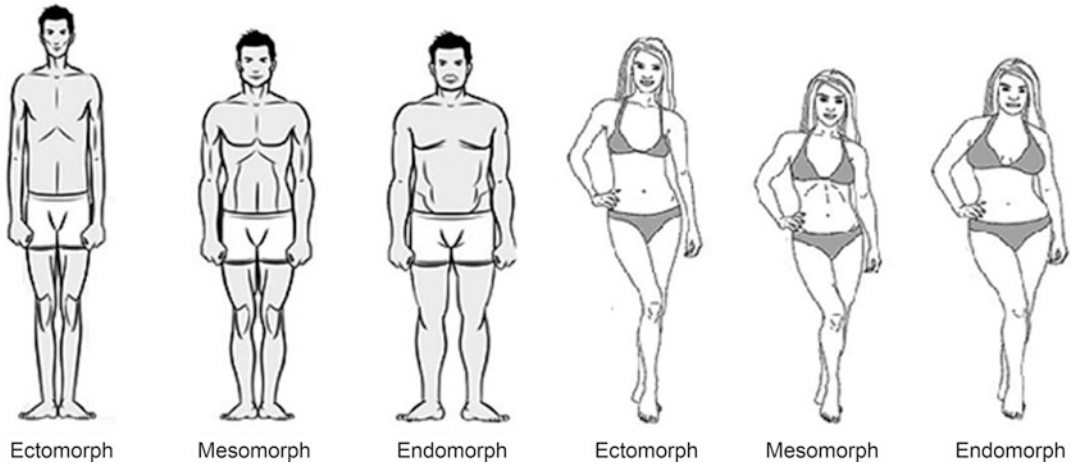
Mesh deformation allows a single mesh to be changed by changing different numerical values. This means that the amount of effort required to make a 3D mesh is quite minimal. However careful calculations and algorithms need to be developed so that the created mesh looks realistic and allows changes within the believable body shape and size. It also requires that the users are provided with some predefined settings as a starting point for their character generation and they build upon that while defining their own characters.

Genetic Algorithm (GA)-Based NPC Making, Fig. 4 The many character options in Elder Scrolls V: Skyrim® (n.d.)

Elitism and Sigma Scaling

The problem with NPC creation with GA is two-fold. We want to create characters that first adhere to a certain set of values over a wide range of values. We then also want the characters to exhibit randomness within those characters so that they fit the selection criteria and yet remain different from each other. One way to solve these issues is to use elitism with sigma scaling. Elitism ensures that the best individuals within a population are retained and they are used to perform crossover and mutation with other members of the population to create new individuals. The benefit of this approach is that the algorithm converges to a solution quickly. The disadvantage of this approach is that the algorithm might get stuck in local maxima/minima from the beginning and might not find out the best solution. The disadvantage however favors its use because an ideal solution is not a requirement for NPC creation. There needs to be a certain degree of randomness which elitism will provide in this case.

Sigma scaling will however ensure that the baseline of the fitness values remains near the



Genetic Algorithm (GA)-Based NPC Making, Fig. 5 Different body types (n.d.)

average (Hancock and Fogarty 1994). Standard deviation ensures that only those values are selected that are closer to the mean. It also requires that there is some order in values that represent the different mesh shapes or modules when defining a character. This is necessary as in real life similar-looking people live in different areas around the world. The differences in height, color, and shape of people vary a little within a local community, but it starts to vary as you move further away. As a result, parent characters that represent a community will need to be defined, and their subsequent generations will produce characters which are random and yet adhere to a defined criterion.

From a fitness point of view, a human body has three body types, namely, ectomorph, mesomorph, and endomorph as shown in Fig. 5. We can clearly see the body structure between the three types which means that their body shape attributes will be quite different from each other. These attributes do not take into account the facial structure and skin color which will also increase the number of attributes required to define a character physically.

As a result, the fitness values for the characters belonging to different demographics are going to be different. GA can use these values to approximate the desired character as requested by the users. This can even play a major role in approximating the child populations based on the interactions between the parent populations. If there is a persistent simulation, it will mean that characters belonging to different demographics are going to breed together through migration which is normally a function used in distributed genetic algorithm implementation.

Conclusion and Discussion

Genetic algorithm has been used in creating characters in unique ways from defining the mental attributes of a character to physical definition. GA works by mimicking the nature's way of natural selection to find the best possible solution to a problem. The usage so far has been to optimizing the AI, for deciding the mental attributes of characters in an RPG setting, for defining the physical appearance of the characters, and for creating optimized morphologies of creatures to improve their movement in a 3D space. By combining these researches together, it can be hoped that GA will be quite useful in the creation and optimization of NPCs in games and also in creating lifelike simulations where characters will improve with time and we are able to see the changes in the population due to breeding, crossover, and mutation and how it affects the overall environment created within a game.

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Geoinformation System

▶ 2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making

Gesture Motion

▶ Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being

Gesture Recognition

▶ Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design

Gesture-Based Interactions

▶ Data Gloves for Hand and Finger Motion Interactions

Global Illumination

▶ Rendering Equation

Global South

▶ Video Game Culture in Cape Town, South Africa

Globalization

▶ Cross-cultural Game Studies

God of War (2018), an Action-Adventure Game

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Synonyms

Single-player game; Action adventure game

Definitions

Single-Player Game = a game that is designed for single-player mode where only one player is expected throughout the entire gameplay

Action Adventure Game = a game that combines core elements from both action game and adventure game genres

Introduction

God of War is an action-adventure game franchise developed by Santa Monica Studios and published by Sony Interactive Entertainment that owns the game studios. This article is about the 2018 God of War in the franchise that was released for PlayStation on April 20th, 2018 (Goldfarb 2018). Following the life of Kratos and how he went from being just a demigod, the son of Zeus, to the god of war in Norse mythology. It is a solo, story-focused game that follows a father and his son on a journey across the nine realms.

Gameplay and Story

God of War (2018) is a single-player third-person action adventure game. A god named Kratos and his son Atreus embark on a mission to spread Kratos' wife's (Atreus' mother's) ashes on the highest peak of all the nine realms of Norse Mythology. Kratos must come to terms with the loss of his wife while also learn how to transition from the finely tuned instrument of war he once was to a caring father for his son. Kratos struggles in deciding whether or not to tell Atreus of Kratos' goodlihood and what that means for Atreus. Eventually, Kratos will be forced to make this difficult decision if he wants to mend Atreus and make him whole.

The game consists mainly of dialogue, actions (fighting), and puzzles. The main weapons in the game consist of Kratos' Leviathan Axe—an axe from Norse mythology that is primarily a cold or ice weapon, and Kratos' Blades of Chaos—twin Greek blades both linked to chains connecting to both of Kratos' arms as a fire weapon. Both the ice and fire weapons are essential for some of the puzzles as well as the fighting because enemies often have a certain damage type: they are either resistant or not. Kratos also has a guardian shield given to him by his wife before her passing. The shield can be used for both offense and defense. Finally, Atreus wields a Talon Bow that can shoot regular arrows, light elemental arrows, or electric elemental arrows. This weapon is important for both combat and puzzle solving.

Gameplay Mechanics

God of War (2018) introduces many new mechanics including new combat mechanics, puzzles, and a system for equipping gear, equipping abilities, and upgrading the gear and abilities (Hornshaw 2021). The combat mechanics involve Kratos using his axe, blades, and shield to fight various enemies. Combat also involves Kratos commanding Atreus to fire his bow at enemies using specialized ammo. The types of weapons the player uses mostly depends on the player's preference as well as the types of enemies. For example, some enemies are immune to Kratos' axe because it is an icy weapon, so the player must switch to either the shield or the blades to defeat the enemy. If an

enemy is immune to the axe, it will usually be more effective to use the blades to defeat the enemy since the blades have the fire damage type.

Unlike previous games in the God of War franchise, Kratos has an armor that can be collected, crafted, and upgraded. These upgrades allow the player to increase Kratos' stats and make him more effective in combat. The upgrades can also be used on Kratos' main weapons to make them stronger while also changing their appearance as player upgrades the weapons. In addition to selecting the type of armor Kratos wears, higher-quality armor pieces provide additional bonuses for the player to exploit. The type of armor the player equips also influences six stats that apply to Kratos. Kratos' stats are strength (damage from standard attacks), runic (elemental and special attacks), defense (reduces damage taken), vitality (increases maximum health), luck (increases chance perks, experience, and money), and cooldown (reduces recharge time of special attacks).

The player also has access to several abilities that may be used along with the weapons. Kratos' axe and blades both can be equipped with up to two abilities each that can be described as a "special move." These abilities can be used as a powerful attack that has a much more significant cooldown than Kratos' basic attacks. In addition to these abilities, Kratos can also have another ability not linked to his weapons but can provide a buff to Kratos. For example, one of these abilities resets the cooldowns of all his other abilities. The player can also give Atreus an ability to use as well where Atreus will summon an elemental animal or animals to attack enemies. The type of animal and the number of animals depend on the ability selected for Atreus (IGN 2018).

Playable Characters

The only playable character in this game is Kratos. Kratos is a former demigod/spartan warrior who eventually became a god by killing the former Greek god of war, Ares. While Kratos is the only character the player can directly control (such as movement, attacks, combos, etc.), Atreus can be indirectly controlled by the player. Kratos wields two main weapons, the Leviathan Axe and the Blades of Chaos. Atreus utilizes a bow. The player is not able to force Atreus to move to certain places, but the player can make Atreus fire an arrow at a target or an area by looking at the target or area and pressing the button or key corresponding with Atreus' shoot action. Atreus will then fire an arrow at the target.

Reception

God of War (2018) has sold about 19.5 million copies as of August 2021. This figure comes from sales for PlayStation consoles alone, as this was before the game was released for PC (Stockdale 2021).

Conclusion

The main enjoyment players receive from God of War is the amazing and thrilling story, combat and leveling systems, the mythology lessons, and the experience of conversing and/or fighting the many Norse mythological creatures and gods (Moore 2022). This title is particularly appealing to those who enjoy a good story and mythology.

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▶ God of War, An Analysis

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God of War, an Analysis

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Synonyms

Hack-and-Slash; Action-Adventure

Definition

Hack-and-Slash = a subgenre of action games that challenges the player to fight hordes of enemies that seem weak individually compared to the powerful player character. They typically ask a player to complete a level filled with minor enemies with a more powerful enemy at the end.

Action-Adventure = A mix of the action and adventure genres. Action-adventure games typically have some fast-paced fighting elements of action games with a story and world of an adventure game.

God of War, a single player game created by Santa Monica Studios on the Bluepoint Engine, was published and released by Sony Computer Entertainment on March 25, 2005. The game is part of an eight-game series spanning across multiple Sony consoles. As of August 2021, *God of War 4* has sold over 19.5 million copies, making it the best-selling PlayStation 4 game as well as the best-selling game in the series.

Throughout the entire series, *God of War* has always been called a Hack-and-Slash or Action-Adventure title due to its extremely gory battles and in-depth storytelling. As a result, the game carries an M for mature rating for every title.

The game begins with no real explanation or character introduction. The main character Kratos simply says, "The Gods of Olympus have abandoned me," and he stepped off the edge of a cliff to lead the player into thinking that Kratos has fallen. The entire storyline for the first game is based around Kratos trying to vanquish the God of War, Ares. Throughout the game, the player controls Kratos and gathers many weapons and magical items and spells for use in their quests. The monsters consist of the undead and other ancient Greek creatures, living, undead, or holy. Due to the naturally bloody storyline and combat features, the target audience for this game are teenagers and adults.

Gameplay can be controversial as there are some players who find that dealing with the same combat mechanic repeatedly can be quite boring, but others think that the new stream of weapons that can be collected keeps things interesting. The mechanics include a simple series of light and heavy attacks, including specialized finishers that are completely different for every enemy the players face. The developers also threw in other special attacks that are unlocked as players progress through the story, such as different magic attacks. Other than these few simple gameplay mechanics, there is not much that *God of War* brings to the table.

Other than the latest installment in the series that takes place in Nordic history, all the previous installments take place in Ancient Greece. The story revolves around the death of Kratos' family, who were killed by Kratos himself under the influence of Ares. Kratos swears revenge for his fallen loved ones and sets out to find the ancient Greek artifact called Pandora's Box. Legend says that this box, when opened, could give any mere mortal the power to kill a god. Kratos plans to use this box to slay Ares for vengeance. Throughout this journey, players meet actual Greek mythological characters, such as Athena, otherwise known as the Goddess of Wisdom.

Levels in this game are not meant to be more than just a quick change of environments, but

rather a smooth flowing of events from one area to another in order to strengthen the effect of the storytelling. To give an example, after the players find out that they need to travel to the Desert of Lost Souls to retrieve Pandora's Box, they are met with a cutscene or backstory that explains why Kratos needs the box in the first place. This cutscene shows Kratos working for Ares by destroying villages who do not follow the ways of God. Only when it is too late does he realize that he is being manipulated by Ares into targeting the village in which his family resides. This cutscene gives the players the reasons for all these events in the game.

The entire game is played in a third-person mode with some cutscenes going into first-person mode. The interface consists of a health and mana bar at the top left corner. Instead of an enemy health bar, players get a finisher button for when an enemy is weak enough to be killed. If there is a boss in the vicinity, a new bar that contains the boss' or bosses' health will appear down at the bottom of the screen that is both larger and longer than the health bar.

God of War was one of the major titles in the Playstation 2's game lineup, and it is conceived as one of the most popular Playstation 2 games, selling 4.6 million copies. Its success has led to seven sequels (Harradence 2019).

However, *God of War* has one major controversy on the subject of nudity in the game (Cooper 2017). While most players thought the mature rating was due to the blood, gore, and violence, some of the player base was met with a surprise when they are given the opportunity to interact with a woman on bed. Although players do not see anything obscene, they can certainly tell what is happening from the sounds and right joystick movements. There are also creatures in the game who lack clothing, and the player is forced to see them naked when fighting them, thus unnerving some players who do not want or intend to see this.

Looking at the *God of War* series, every game in the series so far has received good reviews from GameInformer, IGN, and others. In fact, the latest installment got a perfect 10/10 rating from IGN. For the very first installment, many people opined

God of War, an Analysis, Fig. 1 God of War 1

that *God of War* was the highlight of Playstation 2. Alex Navarro of GameSpot wrote, "*God of War* is one of the best action adventure games on the PlayStation 2, and it should not be missed" (Navarro 2005).

Here is a brief history of the *God of War* series:

The first *God of War* was released in March 2005. It has wonderful graphics for that era of gaming. The game is often called the highlight of Playstation 2's life and is generally highly

God of War, an Analysis, Fig. 2 God of War 2

God of War, an Analysis, Fig. 3 God of War 3

God of War, an Analysis, Fig. 4 God of War 4

recommended. The music consisted of loud choirs followed by other instruments, such as gongs, to give a sense that the main character is powerful (see Fig.1).

The rest of the games throughout the series all share the same concept, but the visuals and sounds have improved. New weapons and abilities were thrown in as the series progressed. The storyline has also changed throughout the series. Kratos goes from killing one god to killing all gods which throws the world into chaos. Here are a couple of images to show the boss fight progressions through the games (see Figs.2 and 3).

The real changes to the game occurred in *God of War* 4, with the introduction of a completely different soundtrack as well as a new style of combat and extremely detailed graphics. There is also a shift from Greek mythology to Norse mythology that introduces new gods, enemies, and landscapes. Krato's appearance was also changed in the new addition:

The following YouTube videos illustrate how music has changed from the earliest edition (God of War 1) to the new installment (see Fig. 4)

God of War 1 Playstation 2 – The Vengeful Spartan: https://youtu.be/yPPU0gcWk38?t=6s

God of War 4 Playstation 4 – Valkyries: https://youtu.be/JbpD7Zn8EPU?t=47m25s

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Graphical Interface

▶ Game Interface: Influence of Diegese Theory on the User Experience

Graphics Applications

▶ Teaching Computer Graphics by Application

Graphics for Branding

▶ Teaching Computer Graphics by Application

Gratification

▶ Videogame Engagement: Psychological Frameworks

Gray Zone

▶ Toxic Behaviors in Online Gaming

Griefers

▶ Griefing in MMORPGs

Griefing

▶ Griefing in MMORPGs

Griefing in MMORPGs

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Synonyms

Anti-Social Behavior; Ganking; Griefers; Griefing; Harassment

Definitions

MMORPGs refer to massively multiplayer online role-playing games, in which many players play cooperatively or competitively within a persistent world. Griefing is generally defined as a type of online bullying within a gaming context and is quite common in MMORPGs. Griefing involves one player intentionally disrupting another player's game experience, through some form of harassment, as they enjoy doing so.

Introduction

Massively multiplayer online role-playing games (MMORPG) are a genre of game that is played online with hundreds to thousands of people playing simultaneously. Each player controls an avatar and can play cooperatively or competitively in the persistent virtual world (Achterbosch et al. 2008; Wolf 2012). In MMORPGs and other online virtual worlds, players may encounter what is known as griefing. This is when one player deliberately disrupts another player's game experience for their own personal enjoyment, with potential in-game gain (Bartle 2007; Foo 2008; Foo and Koivisto 2004). The following is an example scenario that outlines this phenomenon:

> You've had a hard day at work. As soon as you arrive home, you log into the latest MMORPG to relax and wind down for the day. Your in-game avatar is inexperienced, so you approach a virtual farmer and accept their seemingly simple quest that will increase your character's experience points, as well as reward you with a small amount of gold.
>
> You proceed through the forest towards the location of the computer-programmed werewolves that have been terrorizing the farm. Exiting into a clearing you spot the alpha werewolf and engage in combat. You are winning the battle as you outrank the werewolf in melee combat. Just as you are about to strike the finishing blow, out of nowhere a veteran real-life player appears behind you and stabs you in the back, killing you in a single hit. They proceed to finish off the werewolf and collect the winnings for themselves, although to them the loot was secondary to the satisfaction of killing another player and halting their progress.

This scenario illustrates how a highly experienced player may use unfair advantage of

outmatched character progression to surprise attack a wounded and inexperienced player. This type of griefing action is known as ganking, and players have acknowledged that it and many other types of griefing occur regularly in MMORPGs (Achterbosch 2015).

Defining Griefing and Griefers

Bartle (2007) defined a griefer as someone who deliberately did something for the pleasure in knowing it caused others pain. Foo and Koivisto (2004) described griefers as players that engage in play styles that specifically disrupt other players experiences, while Lin and Sun's (2005) definition was similar with the addition that they derive enjoyment from their behavior. Barnett and Coulson (2010) relate a griefer to a bully, stating that these players enjoy participating in anti-social behaviors that disrupt other players' enjoyment of the game.

It is apparent that researchers agree on the overall terminology of the words griefing and griefer, with the perception that three effects need to be present for a player to be considered a griefer:

1. The action is intentional.
2. The action disrupts another player's enjoyment.
3. The instigator gains pleasure from the action.

If these three are present, then the player that causes the action can be called a griefer. Sometimes, the griefer is looking for more than just pleasure and using griefing as an instrument to gain something valuable to them within the game.

Pervasive Griefing Actions

Different types of in-game actions can be attributed as griefing according to the definition above. Ganking, as described in the introduction is one type, and 78.6% of a representative sampled audience defined this action as griefing (Achterbosch et al. 2013), while 9.0% of all players that are subjected to griefing indicated ganking happened to them multiple times per day (Achterbosch 2015).

Verbal Harassment is where chat and voice communications are misused to offend, harass, insult, threaten, or humiliate another player. This was commonly (just over 80%) defined as griefing, and only 19.0% of players that are subjected to griefing had never been griefed in this method. However, the most pervasive type of griefing is spamming, which refers to intentionally filling chat channels repeatedly with messages of low relevance or that are against the game rules. Just over 20% of the sample audience in Achterbosch (2015) indicated this occurred multiple times a day. Other highly pervasive types include spawn camping, ninja looting, and kill stealing. In contrast, a deceptive griefing type known as scamming is not very widespread with 64% having never been exposed to it.

Motivations for Griefing

Achterbosch et al. (2017a) discovered that griefers are motivated by a few factors of potential gain. Pleasure is a common factor among all griefers as prior research suggested, but power, challenge, and/or control are also strong motivating factors for some griefers. For example, the player that retaliates against a griefer with some griefing of their own is challenging the griefer, and through defeating them, feels pleasure. The player that manipulates and deceives does so as they find it pleasurable to control situations and the potential lucrative gains of monetary value serve to enhance their power.

Griefing behaviors can stem directly from the "Online Disinhibition Effect," which refers to abandoning inhibitions and regular social norms when interacting with other people online due to the anonymity and invisibility available and lack of repercussion (Suler 2004). With anonymity, a player's propensity towards griefing increases (Chen et al. 2009). Griefing may be directed at players of either opposing *or* friendly

factions. It was documented that more griefing was directed towards players of the same team within a participant observation of griefing (Achterbosch et al. 2017b). The author joined groups with total strangers on multiple occasions, often known as a "pick-up-group" or PUG, in which many cases of griefing was witnessed. With no fear from team disruption to stealing items to verbal harassment.

Impact of Griefing

Griefing can hugely impact the players subjected to each action. A well-known case revolves around a perpetrator "Mr. Bungle" performing virtual rape. This griefer manipulated the game mechanics and program code to sexually assault multiple inhabitants in an online virtual world (Dibbell 1999). Many players were in shock and some admitted to shedding tears in real-life. In further studies, it has been documented that many different types of griefing affect individuals in vastly different ways and levels of intensity (Achterbosch 2015). For example, 20% of new players subjected to griefing admitted that they played less, 7.1% stopped playing for a time, and 5.1% quit playing the game never to return. Players subjected to scamming and ganking indicated similar (but slightly lower) results. All three of these types of griefing were rated as high to extreme in intensity by roughly one third of the players subjected to them. The impact here represents a growing concern for not only players but also developers looking to keep a strong player base.

Conclusion

With the success of the MMORPG genre, griefing has become an extremely pervasive problem with differing levels of intensity for each griefing incident, and it needs to be addressed. In this article, definitions for MMORPGs, griefing, and the instigators of griefing, called griefers, have been provided. In addition, this article discusses motivations for causing grief, pervasive griefing, the impact, and identifies with a few examples, different types of griefing and griefers.

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- ▶ Online Players: Engagement, Immersion, and Absorption Across Secondary Worlds
- ▶ Sociality of Digital Games

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Group Games Computer Games Industry

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H

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► Bayonetta 2, an Analysis
► God of War, an Analysis

Hack-n-Slash

► Kingdom Hearts (2002): An Analysis

Hades: An Analysis

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Definitions

Hades is a rogue-like hack-n-slash dungeon-crawler game that was developed by *Supergiant Games*, an independent studio in San Francisco founded in 2009, and is best known for their critically acclaimed games *Bastion* (2011), *Transistor* (2014), and *Pyre* (2017).

Development

Hades was first launched as an Early Access game originally in December 2018, exclusively on the *Epic Games Store*, then on *Steam* in December 2019. In September 2020, the team completed their Early Access development and launched v1.0 of the game, additionally adding the game on the *Nintendo Switch* platform. This game was given a Teen rating by the ESRB. The game was designed as an Early Access from ground up. This allowed the community to play a creative and important part in aiding the developmental process of the game, from design, worldbuilding, and storytelling, and helped the game naturally evolve (Schodt 2020).

Storyline

Hades places the player in control of Zagreus, the son of the God of the Underworld, Hades, as he attempts to escape from the depths of the Underworld and reach Mount Olympus. With every attempt that Zagreus makes escaping from his father, the Olympians on the over world aid in his endeavor. There are 30 differently fully voiced

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characters, allowing players to experience the story through thousands of unique events and interactions. The narrative slowly unfolds over the progression of the game, creating different opportunities and dialogue, about ten hours' worth, between Zagreus, the Olympians, and other residents of the Underworld on every run. For instance, Zagreus may meet Eurydice during a run, and when returning to the main house may meet Orpheus, and because the player met Eurydice prior, he may ask to have a message delivered to her, creating another chain of events that the player can seek to uncover.

Successfully escaping the first time will not end the game's story, the player must go again to uncover what happens after that.

Game Mechanics

The game is presented in an isometric point of view. The game features four "biomes" that Zagreus must escape through. Notably, they are Tartarus, Asphodel, Elysium, and the Temple of Styx. When a player starts a run, they begin in a room outside the main house. Afterwards, the player must fight their way through a series of chambers and enemies. The layouts of each chamber are predetermined, though the order of the chambers, as well as the number and types of enemies in the chambers, are different in every run. In some cases, there are chambers in which there are no encounters with enemies; instead the player can shop, restore health, or meet a resident of the Underworld and gain benefits from them. Each level will contain a certain number of chambers as well as a boss. After clearing each chamber, the player will be presented with a reward, which is shown previously above the chamber door. These rewards range from gifts from the Olympians, improvements for those gifts, currency for renovating the main house, upgrades for Zagreus's weapons, keys, and skill-point currency called "darkness" to improve Zagreus' attributes. If Zagreus' health points reach zero, he "dies," and emerges in the main house again. Any gifts granted on a run, besides currency, darkness, and keys, are lost upon death.

The player has six unique weapons to choose from before beginning a run. The player will be able to perform a primary attack, a special attack, and a magic spell. Each chamber has the possibility of earning a reward to upgrade Zagreus' weapons via Daedalus' Hammer. These upgrades range from having more range or damage on a weapon or completely changing how the weapon attacks. Each chamber also has the possibility of granting an aid from an Olympian, called a "boon." These boons improve the attacks of Zagreus based on the theme that each Olympian has. For instance, grabbing a boon from Zeus will grant Zagreus electrifying attacks and abilities, or Aphrodite will grant the "Weak" status, causing enemies to do less damage to the player. Sometimes dialogue between two gods will ensue after picking up their respective boons, and the player will be able to select a combined boon from them. The player also may choose a boon that enables Zagreus to call upon a god's aid when his "God Gauge" bar is filled to a certain amount. Players can mix and match different boons, upgrades, and weapons to optimize their run.

Before starting a run, players can choose and upgrade which attributes Zagreus will have via the Mirror of Night. These are upgraded through darkness and are permanent through each run. For instance, players can choose to add more health, add an additional dash, or add more casts for their magic spell. The player can choose to reroll their darkness to create different combinations of these attributes. They are also able to upgrade their weapons when they have progressed through the game enough and have the materials to upgrade them. The materials can be obtained through defeating the bosses on each level.

After successfully escaping the first time, the player will have the opportunity to ramp up the games' difficulty to earn more rewards via the Pact of Punishment. Through this, a player can turn up the "heat gauge" and add constraints to themselves, make enemies more difficult, and other "punishments." This allows for refreshing re-playable gameplay, and players can test and improve their skills. If players are more geared towards progressing the story, they can choose to enable "God Mode" which makes them stronger on every run.

Reception

The game has been praised for its marriage of "fantastic combat" and engaging story (Macgregor 2020). Vazquez (2020) highlighted that "Hades' narrative is so entwined with its combat is nothing new for the developers at Supergiant Games, who've established themselves as masters of putting your actions in sync with the stories they tell." Supergiant Games' previous game *Bastion* also garnered attention for its combination of gameplay mechanics and branching storyline (Mitchell 2016). As of November 2020, the game has a Metacritic score of 92 out of 100. (https://www.metacritic.com/game/pc/hades)

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Head-Related Transfer Function

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Healthcare Robots

▶ Locomotion and Human Tracking in Healthcare Robots

Healthcare Robots with Islamic Practices

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Synonyms

Islam; Islamic calendar; Islamic prayers; Medical robot; Muslim beliefs

Definition

Artificial Intelligence	Artificial Intelligence (AI) refers to the simulation of human intelligence by machines, especially computer systems.
Decision Support System	Decision Support System (DSS) is the specific application of AI used to support decision-making activities.
Computer Vision	Computer vision is the Artificial Intelligence (AI) system incorporated with other scientific fields, such as signal processing and Neurobiology, to interpret and gain high-level understanding from digital images or videos.
Healthcare Robot	Healthcare robot refers to a machine programmed by a computer capable of assisting humans in the medical field. In addition, it is able to provide care and support to disabled patients and the elderly.
Islamic Practice	Islamic practice refers to five pillars of Islam, which include the statement of faith called "shahadah," daily prayers called

"salah," almsgiving called "zakat," fasting during the month of Ramadan called "sawm," and at least once-in-a-lifetime trip to Mecca called "hajj" (Stefon 2009).

Introduction

People in today's world suffer from various health problems, and as a result, the demand for medication and healthcare services has increased. For example, people suffer from chronic diseases and require continuous medication. There is an issue for a patient to forget and skip their medication routine, for example, an elderly person. Therefore, an automated system for dispensing medicine is essential to avoid the issue. A healthcare robot can autonomously deliver medicine to patients at a scheduled time. As a result, the healthcare robot should also take care of the patient and ensure that the medicine is taken for the most effective treatment.

Motivation and Background

The healthcare industry plays a more critical role in providing effective healthcare treatment to patients at home. The idea of healthcare robots has become a significant invention in this field. Muslims believe that illness and pain are tests from Allah and perceive illness as a trail by which one's sins are removed (Kemp 1996). Therefore, healthcare providers need to understand the Islamic culture for clinical practices in Islamic families. For example, a nurse of the same gender should be cared for, especially when the patient is a female (Alotaibi 2021). Many issues need to be considered in the process of delivering culturally competent care to Muslim patients. These issues affect the design of the Decision Support System (DSS) with computer vision to decide the optimal action the robot needs to perform on Muslim patients. Currently, the standard robots are integrated with cameras that can capture both image and video. Computer vision technology is applied in the healthcare robot to recognize the patient and understand the current situation around the patient. Understanding the current situation will decide the appropriate action that the healthcare robot should interact with patients (Ic et al. 2013). Healthcare robots are programmable to provide medication service to patients at home. For example, one can schedule a robot to deliver medication pills to patients at home. In Muslim society, prayer is the second pillar of Islamic belief. Praying is the most fundamental worshiping practice that Muslims are obliged to take a certain number of times a day (e.g., five times). In general, Muslims can pray at any time of the day for distinct reasons (e.g., busyness, travel, etc.). Therefore, a healthcare robot with the ability to detect prayers by posture recognition is essential for Islamic families. Thus, the robot should recognize a person's posture and approach the patient with Islamic practices. An Islamic-cultural aware robot will significantly improve the robot medication service while also demonstrating respect for Islamic traditions.

Related Works

The first commercially assistive robot is Handy1 (Topping and Smith 1999). Handy1 is controlled by a single switch input for selecting the appropriate action. The Neater Eater assists patients with their meals, including scooping foods from plate to patient's mouth (Song and Kim 2012). Exact Dynamics' iARM technology is applied to assist disabled patients who cannot produce arm movements (Ghobreal et al. 2012). The robot arm is attached to the electric wheelchairs, allowing the patient to control the arm via the controller. The RAVEN II is a laparoscopic device created with objective clinical measures in mind to optimize surgical performance (Hannaford et al. 2013). MiroSurge is being developed by the German Aerospace Center (DLR) to be very adaptable in terms of the number of surgical domains, arm-mounting sites, a number of robots, control modes, and capacity to integrate with other technologies (Hagn et al. 2010). The ARMAR III is developed to assist patients in a household

environment, such as interacting with people and manipulating household items (Asfour et al. 2006). Care-O-Bot 3 is a robot for assisting people in their daily lives (Reiser et al. 2009). A flexible torso enables butler-like motions such as bowing and nodding, an arm and gripper for manipulating items, a tray for carrying and transferring goods, and a tray for holding and moving objects. As mentioned above, most robots are trained to respond to specific duties to assist patients. As a result, there has been considerable advancement in the ability of healthcare robots to perform medical services while also exhibiting respect for patients' cultural and religious values, such as in Islamic nations.

Structure of Learning System

The system architecture of healthcare robots is described as follows. The healthcare robot usually sends the data to the Robot Decision Services (RDS) for deciding which action the robot should take. The decision system on RDS consists of three subsystems: the Face Recognition System, the Prayer Time Decision System, and the Prayer Posing Detection System. These three subsystems will cooperate to determine the optimal action for the robot. The optimal action will be sent back to the robot along with the action code. The description of subsystems is presented as follows: (1) Face Recognition System (FRS) is responsible for recognizing the patient's face from the given image. The clear face image of users must be first submitted to the system. Technically, all face images are encoded in high dimensional space so that the distance between two vectors represents the similarity of two different face images. All face vectors are recorded in the Face Database. (2) The Prayer Time Decision System (PDS) is responsible for decision-making on the prayer time. It annually updates the Prayer Time Database from the public Islamic calendar service. PDS is required in this system because the robot should not interfere with the user during prayer time. The system also supports any time zone and adds the predetermined offset time to each praying schedule. (3) Prayer Posing Detection System (PPDS) is responsible for detecting and recognizing the posing of the patient. It analyzes the image and determines the posing of the patient at any time of the day. Object detection techniques are used to detect four main postures in Islamic prayer, Qiyam, Ruku, Julus, and Sujud, but it should also be able to distinguish the four main postures from traditional postures. For example, body centroid detection is used to identify whether the human object is moving and avoid false detection on similar posture such as walking/standing as Qiyam and sitting as Julus. A machine learning model should also be implemented to detect and recognize some restricted posing set, such as lying down, standing up, sitting down, and walking.

The process of healthcare robots is described as follows. When it is time to take medicine, the robot will continue searching for the patient in the house. If the user is identified and located, the robot will send the request to RDS to determine the optimal action in real-time. The request data that is sent to the server consists of the image from the camera sensor and the timestamp. Technically, the images are converted into string format before sending through the network connection. Then, the robot will act upon the decision response from the server.

The process of RDS is described as follows. RDS can be considered a server-side web Application Programming Interface (API). RDS listens for the request from the robot. After receiving the data from the robot, RDS will check the validity of the request message. If the request message is not matched, the server will send the error message back to the robot for collecting new data. Then, the image is decoded and sent to FRS. If the face in the image is not the targeted patient, RDS will send the message to inform the robot that the following action is to continue searching for the patient. RDS will then check for the prayer time by considering the image's timestamp, current time zone, and praying schedule. If the timestamp is between the praying time interval, the system will go to a room to search the patient. However, the prayer time may differ from the praying

schedule for many reasons. The system also determines the current action of the user to avoid interference in between the praying processes. The current action of the user can be determined from the image. If the praying pose is detected, the system will wait until the patient finishes Islamic praying.

Cross-References

▶ Locomotion and Human Tracking in Healthcare Robots

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Healthcare Training

▶ Nursing Education Through Virtual Reality: Bridging the Gap

Hearthstone: A Collectable Card Game Through the Lens of Problem Solving

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Synonyms

Collectable card game

Definitions

Collectable Card Game = a type of strategy game where players collect cards to form a custom deck to overcome challenges presented by other types of decks.

Introduction

Hearthstone is a collectable card game that does a good job of showing the lens of problem solving, which is all about the problems that a game poses to a player, and how the game continues to make the player solve new problems. In Jesse Schell's

book "The Art of Game Design: A Book of Lenses," the Lens of Problem Solving states that "To use this lens, think about the problems your players must solve to succeed at your game, for every game has problems to solve." (Schell, 2019) The Lens of Problem Solving requires us to ask the following questions:

1. What problems does my game ask the player to solve?
2. Are there hidden problems to solve that arise as part of the gameplay?
3. How can my game generate new problems so that players keep coming back?

Gameplay

In Hearthstone there are two main ways to play, multiplayer (which includes ranked and unranked) and solo adventures (which include raids and challenges), both of which have a max card limit of 30. In solo adventures, the developer directly interjects the problem solving, rather than allowing it to fall unto the players to create and solve problems for each other. The main content in solo adventures is raids, which pits the player up against a variety of bosses with varying difficulty, and challenges, where the player is put against a group of weaker enemies while also having less choice on how they're going to approach the enemies. With raids, players make their own decks around each individual boss, while with challenges, the player is given a deck, and as they progress through enemies they are given more cards and gameplay options to mix with their existing deck to make as strong a deck as possible to defeat the later enemies.

Raids require the most direct problem solving. The game puts a boss with a unique ability and unique move set in front of you and you have to build a deck around that. This can lead to some insane decks being made. A good example is one of the earlier bosses in the Icecrown raid; this boss has 30 health (a normal amount), and a free, spammable ability that allows him to go back to 30 health every turn. So, the problem is how to defeat an enemy that can heal so much damage for free. The solution is simple in concept but difficult in execution. Dealing 30 damage in a single turn. Some classes have it easier than others. Priests, for example, can just put a high health minion onto the field, increase its health to be at or above 30, then set its attack to be equal to its health, allowing it to just one shot the boss. While other classes, like mages, have to set up intricate combinations of cards, one example being having cards that reduce the mana cost of a spell and another card that allows you to cast that card until you run out of mana. The real challenge there being that you have to get quite a few cards out at the same time or risk having important cards being destroyed before you can use them.

Challenges start the player with a smaller deck to work with, but also place them against much weaker opponents. After each opponent, you choose between three sets of three new cards that you add into your deck. These cards ignore the normal limitations of the game, allowing you to have more than two of the same card. On top of this, after the first and fourth enemy defeated (out of eight), you are given the option to choose a buff. These buffs can be anything from increasing your health significantly, or giving you extra mana at the beginning of the game. With the way challenges are set up, the problem solving is less reliant on the cards that you personally own, and more reliant on your own skill and knowledge of the game as a whole. However, it does introduce a luck element, where you might not get the most optimal options, and struggle because of it.

Multiplayer Mode

In the multiplayer mode, the game is constantly updated with new cards and interesting meta-breaking combinations to find, so you get your average competitive game where both players are set against each other with plenty of opportunities to outplay the other. The ranked mode has 25 ranks that you have to go up before you can reach the "legend" rank, and start playing to be placed as one of the best players in the world.

In closing, Hearthstone has the entire problem solving of a multiplayer game mixed with varied

and difficult single-player content that can be very challenging to figure out. It has a very large amount of cards to make new strategies and there will always be something that requires a new deck to beat.

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Hidden Markov Models

► Machine Learning for Computer Games

High-Performance Many-Light Rendering

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Synonyms

Many-light rendering; Virtual point light

Definitions

Many-light rendering is a class of efficient image synthesis algorithms that try to render a scene with a large number of light sources. These light sources can be real lights in the scene, or virtual point lights (VPLs) approximate light transportation of current lighting conditions.

Introduction

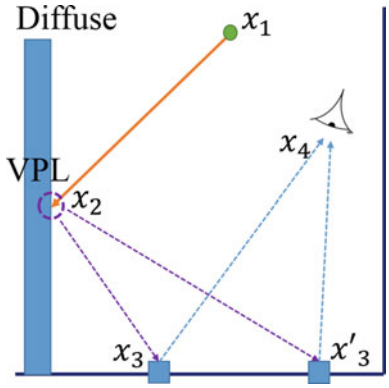
Full global illumination is considered the crown of rendering. Creating high fidelity global illumination efficiently is one of the most important topics in photo-realistic image synthesis. In order to calculate a high dimensional integration in the rendering equation proposed by Kajiya (1986), a huge amount of computational power is needed, which prevents the pure path-tracing group of methods from implementing in an interactive to real-time systems. In the other hand, such tracing algorithms are often not regular, which will cause workload balance problems or irregular memory access problems on parallel hardware architectures especially current GPUs, thus harm the scalability of the algorithm.

In this entry, we will introduce many-light rendering, which is one of the simplest and most elegant solutions in the global illumination field that can increase scalability while still being able to generate photo-realistic images. The main idea of many-light rendering is to split the rendering into two steps: The first step is to generate a massive amount of virtual-point-lights (VPLs) in the scene according to the original rendering equation or path space integration framework proposed by Veach (1997). The second step is that for each pixel, the irradiance will be collected and accumulated from all VPLs to approximate the final results. Among all the physically based rendering techniques, many-light rendering methods are considered best suitable for fast preview and iteration situations, which are also often suitable for GPU-based parallelization scheme.

Many-light rendering algorithms can also be applied in a scene with a large number of actual light sources, which is becoming more and more common recently. Scenes illuminated with numerous actual light sources can also migrate algorithms from the VPL-based global illumination algorithms. Some recent advances can be found in literatures such as Dachsbacher et al. (2014), Bitterli et al. (2020), and Yuksel (2020).

Many-Light Rendering: Paths in VPL Framework

Keller (1997) is considered the beginning of many-lights rendering. VPLs are generated by



High-Performance Many-Light Rendering, Fig. 1 Illustration of the generation of VPL. A VPL x_2 is generated from the light source point x_1 during generating step. It will then illuminate other surface points such as x_3 and x_3. It will be collected to the pixel plane point x_4 on the camera

light path random walk in the scene. Figure 1 is a simple illustration of such a VPL path. For the *i-th* VPL x_i generated by vertex x_{i-1}, among total VPL number of n, and an eye vertex x_e, the radiance reflected at eye path intersection point (also referred to shading point) $\overline{x}$ is:

$$L = \sum_{i=1}^{n} f(x_{i-1} \rightarrow x_i \rightarrow \overline{x}) \\ \alpha_{x_{i-1}} G(x_i, \overline{x}) f(x_i \rightarrow \overline{x} \rightarrow x_e)) \quad (1)$$

where L means radiance coming to eye vertex $L(\overline{x} \rightarrow x_e)$, $G(x_i, \overline{x})$ is the geometry term containing the visibility term $V(x_i, \overline{x})$. $\alpha_{x_{i-1}}$ is the virtual light contribution of vertex x_{i-1}, which is defined as a Monte Carlo style sampled path contribution of a random walk path sequence generated from the light source.

The two steps of a VPL-based many-light rendering are

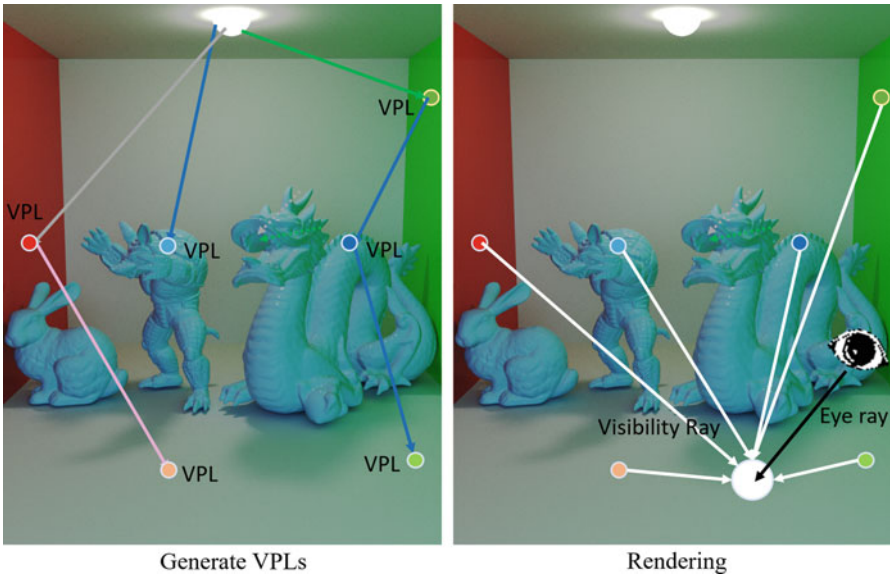
- Generate a large amount of VPLs in the scene. Choose the light sources and starting position randomly, then shoot a VPL ray from the point into the scene. If the intersection surface is diffuse, record the VPL with corresponding probability, BRDF (Bidirectional Reflectance Distribution Function), and geometry term on the scene. Trace the ray with a Russian roulette termination condition.
- For each rendered point, collect illumination from all VPLs. Iterate each VPL and conduct a visibility test to determine if the VPL is visible from the rendered point, then compute and accumulate the contribution from each VPL.

Figure 2 is a simple illustration of such two steps.

Another situation that needs to calculate a huge amount of light is when there are actually many light sources that exist in the scene. These two problems share a similar computing model, thus are often classified in the same category. To distinguish these two different end applications, we refer to the VPL-based global illumination scenario as many-light GI, and the second scenario as many-light DI (direct illumination from actual light sources).

The first step of many-light GI is to distribute VPLs in the scene. There is a lot of research studying how to efficiently distribute VPLs in the scene. Georgiev and Slusallek (2010) introduced a simple reject-sampling method that will filter out unimportant VPLs. Hasan et al. (2009), on the other hand, are trying to generate virtual light sources that can avoid the singularity problem, which will cause bright spot artifact in the final rendered results.

For the second step, our problem is more clear: how to efficiently accumulate energy from a massive amount of virtual point lights distributed at various regions in a complex scene geometry. The basic method is to calculate the color of N samples, from every light source (VPLs or actual light sources) of a total number M, which indicates at least $M * N$ raycast and lighting calculation. The $O(N * M)$ algorithm is not acceptable when there are massive samples on the pixel plane and a large number of light sources in the scene, especially for interactive and real-time applications. So we need to make approximation or calculate the accumulated energy in a clever way to reduce the cost and increase the scalability of the algorithm.



High-Performance Many-Light Rendering, Fig. 2 The two steps of a general VPL-based illumination

High-Performance Many-Light Rendering

From the previous section, we know that to gather the full lighting information for a specific point in many-light rendering, a huge number of raycasts will be performed to calculate the visibility between the shading point and light sources.

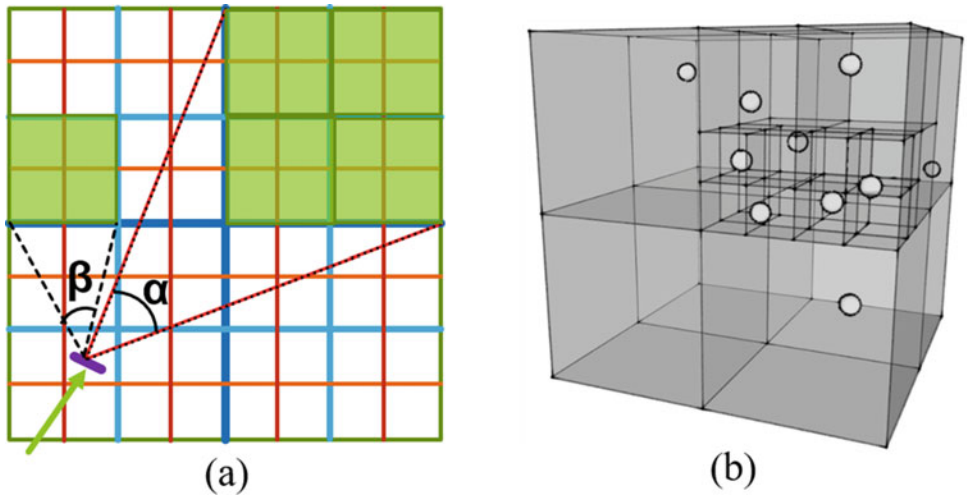
Cluster-Based Method

An observation is that samples and light sources (or VPLs) that are near to each other often share similar visibility and lighting information. A natural idea that can help to solve the performance problem is to cluster nearby similar VPLs together to form stronger lights to decrease the necessary number of visibility raycasts (Fig. 3).

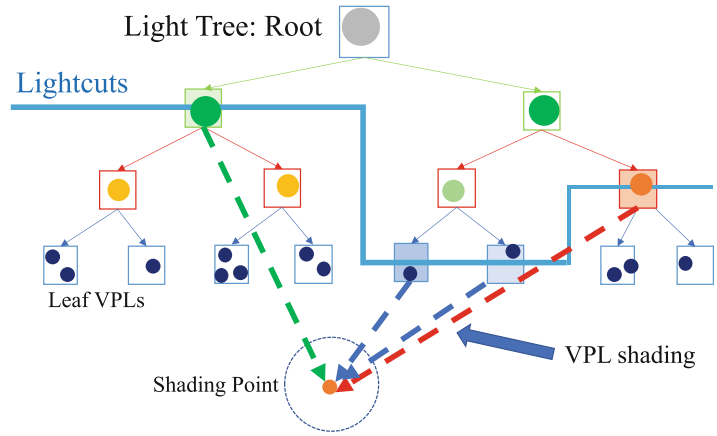
Walter et al. (2005) is an early work on the approximation of VPL clustering. All lights or VPLs will be constructed into a tree structure called a light tree. A light cut means all the nodes that have been chosen for a specific shading point. Figure 4 shows how a shading point is illuminated by a hierarchically constructed light tree. From a certain shading point's perspective, the visibility and contribution of faraway nodes less than a threshold solid angle will be calculated as a whole to reduce computational cost. The nearby lights that exceed the solid angle threshold may need to be calculated separately to increase the accuracy of the illumination.

Other works such as Ou and Pellacini (2011), Walter et al. (2012), and Bus et al. (2015) dive into this idea further by exploring theories and techniques to cluster shading points as well. The scalability of many-light rendering methods is significantly improved with these hierarchical cluster-based methods.

Another important group of techniques that tries to cluster lights and shading points by another formulation is the Matrix Row-Column Sampling (MRCS) method proposed by Hassan et al. (2007). It formulates the many-light rendering problem into a matrix row-column sampling problem from the VPL evaluation matrix M. The row of M is all the shading points, and the column of the matrix represents all the VPLs. Thus, the entry $M(i, j)$ is the contribution from VPL j to the shading point i. Hašan et al. (2007) observed that matrix M is often low rank, which means that it can be compressed to a smaller matrix. Shading points and VPLs will be clustered through the



High-Performance Many-Light Rendering, Fig. 3 (**a**). VPLs can be clustered together with a certain error-bound constraint, thus the similar project angles from different distances. VPLs can be clustered together with a certain error-bound constraint. (**b**). Octree is a famous spatial subdivision structure that can be used to construct such light tree



High-Performance Many-Light Rendering, Fig. 4 Light cut of a light tree. The shading point will be shaded by the nodes and leaves on a specific light cut calculated with error bound

compressing algorithm. To do such a compress, the author proposed to do a row-column sampling algorithm that can effectively create the low-rank matrix which can be evaluated efficiently.

Huo et al. (2015) is a matrix-sampling-and-recovery scheme developed from MRCS that aims to efficiently accumulate the illumination contribution by sampling and reconstructing the low-rank illumination matrix as well as predicting visibility from spatially correlated shading points and lights. Huo et al. (2016) explore the locally coherent nature of scattered lighting in heterogeneous media. Nabata et al. (2016) proposed an error estimation framework for such a clustering scheme.

Sampling-Based Method

Clustering lights together is a biased approximation with a bounded error, which may not meet the demands of high-quality-image-synthesis tasks. To generate unbiased synthesis with a huge amount of light sources, an unbiased Monte-Carlo integrator is needed. There is a group of methods that try to find important lights through sampling in an unbiased way, and here we will

introduce some of the important works developed recently.

Moreau et al. (2019) proposed the many-light sampling method that maintains the hierarchical light sampling data structures. Light sources are organized in a bounding volume hierarchy (BVH). They will be stochastically traversed during the shading phase. Lights maintained in a two-level light acceleration structure will be stochastically selected by evaluating an important function. They achieve two orders of magnitude faster than the original off-line implementation.

Yuksel (2020) presents a stochastic light cuts technique that can replace the sampling correlation of light cuts and replace it with noise to resolve bias issues in light sampling. The basic idea is that for each node in the light tree, choose the representative light in a stochastic way to avoid extra bias. They will also be chosen on the fly to avoid extra storage of light tree. Yuksel also developed a hierarchical importance-sampling scheme that can compute the light probabilities using the light tree during the lighting evaluation at a given point on the fly.

A recent important work is Bitterli et al. (2020). This work proposed a spatiotemporal reservoir-resampling method that can be applied in many-light condition. The main idea is based on a resampled importance sampling (RIS) technique that can effectively reuse statistics from temporal and spatial neighbors for each pixel's direct light sampling PDF. Combining with a biased estimator, this work will be able to synthesis photorealistic images for scenes containing dynamic emissive triangles on GPU in real time.

Conclusion

In this entry, we introduced the basic theory and techniques about an efficient set of algorithms for photorealistic global illumination: many-light rendering problems. We summarize cluster-based and sample-based methods that can improve the efficiency of this algorithm significantly. Both came with a price: The cluster-based methods generate an approximation of the global illumination with a bounded error by traversing hierarchically constructed light tree or shading point tree but will bring extra bias to the final results, while the unbiased Monte-Carlo estimator sampling the light source will be able to generate unbiased results but will bring noise due to the variance which may not be suitable to use directly for interactive applications. In practice, these two groups of methods can be combined together to leverage accuracy and performance.

Cross-References

- ▶ 3D-Rendered Images and Their Application in the Interior Design
- ▶ Raycasting in Virtual Reality
- ▶ Rendering Equation

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History of Augmented Reality

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Synonyms

Augmented reality; Computer-mediated reality; Mixed reality

Definition

A form of computer-mediated reality that superimposes images into the view of a user. It uses the existing environment, complementary imagery, and interactivity to bring an enhanced experience.

Introduction

Augmented reality is a form of technology that falls under the category of computer-mediated reality. Like its fellow technologies, such as virtual reality, this technology allows users to interact in a computer environment. This technology, however, allows users to interact within their existing world, instead of a fully immersive one. Only a few decades old, the technology still has had an interesting path to its more mainstreamed state that we enjoy today.

History of Augmented Reality

The first reference to Augmented Reality technology is said to come from the author of *The Wonderful Wizard of Oz*, Lyman (L.) Frank Baum in 1901. From another work of Baum's called *The Master Key*, a demon provides a character with the "Character Marker" – which is a pair of spectacles that would place a "G" or "E" on the foreheads of each person that they would meet, which correlated to whether they were good or evil. There was also "W" for wise, "F" for foolish, "K" for kind, and "C" for cruel. When asked who discovered the device, the demon informs the reader that: "It is a fact that has always existed, but is now utilized for the first time." (Javornik 2016)

Much like the virtual reality, some of the technologies that brought augmented reality to life overlap and have existed before the creation of the specific technology itself. In fact, these technologies such as virtual reality, augmented reality, and others are contained on a spectrum and can be referred to as mediated reality. Two less recognized forms of this mediated-reality space are modulated reality and diminished reality (Grover 2014). Overall, what this field of mediated reality allows for is the ability of the computer to add or subtract from our perceived reality – adding into the experience until it is completely immersive, such as in virtual reality.

Similar technologies that fueled the development of virtual reality also lay behind the inspiration for augmented reality. In 1929, Edward Link created the "Link trainer," which was an

electromechanical flight simulator that encapsulated the individual into a replica cockpit. During WWII, 500,000 pilots improved their skills by logging hours of initial training on 10,000 "Blue Box" Link Trainer machines. Later, the Sensorama was created in the mid-1950s by Morton Heilig, a cinematographer that patented the device later in 1962. It had stereo speakers, a stereoscopic 3D display, fans, smell generators, and a vibrating chair. Using his background in cinematography, six short films were created by Morton Heilig himself to accompany the device.

In the 1960s and 1970s, more advancements were made on the technological front of these industries. These include a continuation of Morton Heilig's work within a device called the Telesphere Mask in 1960. More attention was beginning to be paid as a pair of Engineers from Philco Corporation, Charles Comeau and James Bryan, created the Headsight in 1961. It was developed for immersive, remote viewing of dangerous situations by the military. The 1960s also saw the writing of the Ultimate Display concept by Ivan Sutherland. His design housed a computer-generated virtual world that was maintained in real time. The 1965 paper laid the foundation for concepts that represent the core blueprint for these types of mediated reality technologies today. However, it was not until recently that Augmented Reality began to take off.

The 1990s is when Augmented Reality truly came into fruition. The term was first coined that year by Boeing Engineers' Tom Caudell and David Mizzel (Rauterberg 1990). This is one year after virtual reality received its official title from Jaron Lanier. From the coining of its term in 1990 and every few years, major developments were made. It was in 1992 with Louis Rosenberg that steps were taken towards a functional augmented reality system. It was called Virtual Fixtures and was developed through the US Air Force Research Laboratory. His research showed that an AR system could enhance performance. Rosenburg is dyslexic and attributes some of his success in technology to this trait. In fact, his issue with handwriting is what spurred him towards the computer in the first place (Rosenberg 2016). He continued his research at Standford University, showing further proof that virtual overlays helped the user interact in the real world with enhanced capability. His moral underpinnings as an animal rights supporter and vegan mostly likely aided in his passion as he later develop the first VR surgical simulators that helped to reduced the use of animals for medical training (Rosenberg 2016).

In 1994, Steve Mann, recognized more as the father of wearable computing, also cemented himself into the fathering of augmented reality with his invention of the Digital Eye Glass and mediated reality. (Mann 2018) At one time during work at MIT, he would wear 80 pounds worth of equipment to class as he worked on wearable technology and interacting technology with the environment (Mann 2013). A believer that technology should be organic to humans, rather than humanity learning the ways of computing, inspired him to integrate these two worlds.

In 1996, Jun Rekimoto invents the 2D matrix markers for AR objects, also known as CyberCode. It is a technique that allows for augmented reality to identify real world objects and estimate their place in a coordinate system. The technology uses barcodes to identify large numbers of objects. This additionally makes it so that objects can have useful information associated with them when interacted with. The technology kept on maturing as the decade ensued. One year before the millennium in 1999, Hirokazu Kato created ARToolKit at HITLab, which started an open source computer tracking library that created augmented reality applications that could be placed into the real world.

The first augmented reality game was created by Bruce H. Thomas and was called ARQuake. It was demonstrated at the international Symposium on Wearable Computers in 2000. Smaller developments were made in the technology that continued to bring it to more market appeal, but it was not until 2013 with the announcement of Google Glass that the technology began to gain more mainstream hype. Even the Google Glass creation was met with some criticism, Steve Mann said during the Augmented World Expo in Santa Clara that the technology was more a generation one device, similar to other prototypes of the past (Hollister 2013).

What was the moment that sent AR over the edge? Well, one could say that it was the breakthrough phenomenon of the Pokemon Go game that allowed the technology to spread its wings in the full twenty-first century – at least in a household use sense. We may begin to see more inclusion of interesting advancements in augmented reality, as it has been dubbed the eighth medium – coming on the heels of mobile technology, internet, TV, radio, cinema, recordings, and print. This technology will be used in multiple ways, as it is expected that one billion people will begin interacting the technology by 2020. The Microsoft Hololens was finally delivered in 2016 after its initial introduction in 2015; the developer's kit is now available and the technology is seeking to upend some of the ways that we have traditionally approached augmented reality.

The technology places images and objects into the environment to interact with and is dubbed by Microsoft as a mixed reality system. There are exciting developments surrounding the technology, for example, an individual could see through your device to guide you through a repair job (Statt 2015). One could also Skype with another person and walk around freely, and not worry about having their full field of view obstructed. The device also presents educational, gaming, and a fundamental change in how computing is expected to interact – as the system is completely self contained and independent from an underlying computer. This is unlike virtual reality systems like the Oculus Rift that tether you to a desktop computer and corrals the users within the range of sensors.

What augmented reality will provide is an exciting link between traditional computing interactions and the real world. There is the ability to try on clothing or glasses before you purchase them from an online venue or store, or to try on several outfits at the drop of a hat. There are educational advantages and integration into our self-driving car future. As more recent phones from Google, Apple, and the like begin to integrate more augmented reality into their latest releases and software updates, then there will come a plethora of new applications and interactions within the technology.

These mediated reality technologies are set to make $162 billion by 2020 (Intelligence, BI 2016). This growth is poised over the distribution of the technology itself, as it does require hardware purchases. The wearable market, which slightly overlaps in this technology, is estimated to sell $34 billion dollars worth of devices by 2020, compared to the $14 billion in 2016 (Lamkin 2016). The industry is on the rise and as we continue to integrate incredibly more powerful watches, glasses, and cell phones into our daily lives, then there is a way this technology could deepen the experience already enjoyed. Perhaps one day, built into every pair of glasses could be a "Character Marker," as first forecast in 1901 and already in use in some facial recognition smart glasses today.

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History of Virtual Reality

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Definitions

The term "virtual reality" was coined by Jaron Lanier in 1987 during a period of intense research in immersive technologies (Virtual Reality Society 2017). Lanier owned a research company pioneered in 3D graphics and immersive interactions that produced the first commercially available virtual reality equipment such as virtual reality glasses and data gloves.

Some of the artifacts mentioned in this entry for an historical account of VR (virtual reality) are dated far earlier than 1987, since they were chosen according to criterion that the artifact creates an immersion effect primarily based on sense of vision. Using a technology-oriented approach in relation with the arguments in contemporary research, Garner (2018) suggests that stereoscopy, field of view, and synchronized multimodality are vital contributors to presence and immersion which are two of the most significant elements of VR experience. To enhance immersion and presence, an artifact may also employ auditory, olfactory, or somatosensory stimuli besides 2D (two-dimensional) wide angle field of view or 3D (three-dimensional) vision.

While the definitions given here were limited to the technical progress, devices, and products in relation to VR; some authors (Gigante 1993; Jerald 2015; Steinicke 2016) mentioned the fictional representations of the virtual worlds in literature, cinema, and television as a part of VR history.

History

Mechanical Precursors

History of VR (virtual reality) can be taken as far back to 1793, when the Irish painter Robert Barker exhibited his panoramic paintings at the rotunda in Leicester Square, which is the first building purposefully constructed to view the paintings located on the inner facet of circular walls, with internal staircases and platforms (Benosman and Kang 2001). The building itself is an immersive technology, patented in 1796 by Barker. It is followed by a sequel of similar display methods such as Franz Niklaus König's Diaphanorama, Daguerre's Diorama, Charles A. Close's Electronic Cyclorama, Thomas Barber's Electrorama, Lumière Brothers Photorama, and Grimoin-Sanson's Cinéorama (Uricchio 2011). The Cinéorama, appeared in 1900 Paris

Exposition, consisted of ten synchronized 70 mm motion picture projectors screening a 360° moving images on the walls of a circular space, where an audience of 200 viewers can be located at the center in a gondola-shaped platform to experience a balloon ride over Paris. Some other immersive setups in Paris Exposition were Trans-Siberian Railway Panorama and the Mareorama, both used moving panoramas painted on canvas to simulate motion within traveling experience. The nineteenth century panorama evolved into a mass media while people around Europe visited various panoramic displays immersing themselves in views of nature, landscape, and historic events (IJsselsteijn 2005). These circular display techniques of panoramic vision evolved into widescreen cinema in twentieth century.

Stereoscope was another early invention of nineteenth century that pioneers virtual reality technology. In 1838, Charles Wheatstone, Professor of Experimental Philosophy in King's College (London) devised two mirrors located at 45° to the viewer's eyes, reflecting two slightly similar images. Images were drawings, since it was a year before Daguerre (who was also the director of Dioroma mentioned above) established a practical photographic process called daguerreotype. Later in 1841, Wheatstone made experiments with photographs taken with a single lens camera from different angles (Wade 2012). In 1849, David Brewster has developed a handheld stereoscope using prismatic lenses besides a binocular camera to take stereoscopic photographs. Brewster (1856) credits the first functional stereoscope to Mr. Elliot's design in 1834, which is a stereoscope that does not employ any mirrors or lenses: the ocular stereoscope. Referring to Wheatstone's device as reflecting stereoscope, Brewster named his own invention as lenticular stereoscope. The Brewster stereoscope had drawn a huge public attention. A London based company sold more than half a million stereoscopic views from 1856 to 1858 and a million views in 1862 (Bendazzi 2016: 15). The public attention in stereoscopes led to attempts to combine stereoscopic views and motion, such as Claudet's and Duboscq's efforts in 1852, which was the earliest patent application for a motion-picture stereoscope (Wade 2012; Zone 2014: 26). However, neither of these attempts for a motion-picture stereoscope resulted with a commercially successful product, due to the "contrast between the ease of inducing apparent motion and the difficulty of seeing depth in sequences of briefly presented stereoscopic images" (Wade 2012). Stereoscopes stayed in use until early 2000s as an entertainment and educational technology and finally a children's toy, to view stereoscopic images printed on cards, film, slides, and reels. The design of Brewster evolved into phone-based VR products after 2014, which employ mobile phone screen to show stereoscopic images instead of printed images (Jerald 2015: 16).

Stereoscopic projection artifacts should also be mentioned within the early efforts that can be related to virtual reality. Louis Ducos du Hauron, the inventor of color photography, enhanced the "anaglyph" methods that can also be used for forming three-dimensional visuals based on encoding each eye's image using filters of different colors. The term "anaglyph" was first used by de Hauron in 1890s, but the principles were known since as early as seventeenth century (Zone 2014: 55). The first stereoscopic projection based on anaglyph method was described by Wilhelm Rollman in 1853, who could have been the first to project images with complementary colors but the first projector that is known to be actually built was made in France by Charles d'Almeida, in 1858. In nineteenth century, the methods based on the polarization of light were also employed to display three-dimensional images. The principles of polarization had been known since seventeenth century, but a British physicist named John Anderton is credited to be the first to use it for projection of three-dimensional images with his mechanism patented in 1895.

Immersive Movies

During the first two decades of twentieth century, motion pictures became a popular entertainment medium. However, until 1922, there was not a successful product of 3D motion pictures that has developed beyond prototype stage. In September 1922, the first 3D feature film, *Power*

of Love, was screened to an invited audience at Ambassador Hotel Theater in Los Angeles. The film is taken by Harry K. Fairall's camera which was later patented as "Binocular Nonstop Motion Picture Camera" in 1930. Stereoscopic viewing was achieved using anaglyph method, in which viewers use complementary colored glasses. Another anaglyph based 3D motion picture were Plasticons by William Van Doren Kelley's stereoscopic camera pair, followed by Jacob Leventhal and John Norling's Plastigrams, which were animated cartoons that obtained a large audience in multiple theaters. Success of Plastigrams created a demand for more novelty 3D film, which was filled with Stereoscopics created by Jacob Leventhal in 1925, followed by Audioscopics in 1935. Although the commercially successful examples of 3D cinema was based on anaglyph method, there were attempts to use alternate frame and polarized viewing technologies. The Teleview of Laurens Hammond was a public 3D motion picture screening in New York, in December 1922. This 3D motion picture system installed at Selwynn Theater used a twin-strip 3D camera with two lenses, dual projectors, and a revolving electrical shutter affixed to the armrest of each spectator's seat. The Zeiss Ikon company based in Dresden Germany used polarized 3D methods. Working in cooperation with the State Establishment for Physics and Technology of Braunschweig, Zeiss Ikon developed a high-speed twin 16 mm stereo motion picture film system for use at the Berlin Olympics of 1936; while in 1935, Otto Vierling developed a single-strip 35 mm stereo camera system using a prism in front of the lens for Zeiss Ikon, viewed using polarized glasses (Zone 2007).

Wide screens were alternative to 3D stereoscopic vision in order to create an immersive experience. In 1950s, the motion picture industry in USA was seeking for novelty in order to compete with television. Wide screen cinema was a solution to attract viewers to movie theaters. Developed in 1952, Fred Waller's Cinerama used three simultaneously shot 35 mm films that were synchronized and interjoined into a single wide image projected on a huge curved screen by three projectors, forming a 146°–55° viewing angle for the spectator. The curved screen consisted of vertical strips angled toward the audience to prevent light reflected from one edge of the screen to wash away the image on the other edge. Originally, Waller developed an 11 projector system called Vitarama for 1939 World's Fair in New York and worked on five projector systems for military training purposes during WWII. Although the wide screen technologies revoked the interest into movie theaters, systems like Cinerama, such as its successors Cinemiracle, Thrillerama, and Wonderama which were based on multiple cameras and projectors, were not widely accepted due to production and projection costs. The Cinemascope technology became popular, which is based on single camera and projection that uses an anamorphic lens to create a wide screen picture (Reeves 1982; Patterson 1973).

Norton Heilig brought the immersive viewing experience one step further, with his "Telesphere Mask" and "Sensorama." Patented in 1960 and 1962, these two inventions can be regarded as multisensory theater with 3D images, stereo sound, wind, smells, and vibrations, but the interactivity was missing (Bown et al. 2017).

Telesphere Mask was described as "Stereoscopic Television Apparatus for Individual Use" in patent documentation, with a pair of adjustable lenses, a pair of television tube units, a pair of earphones, and a pair of air discharge nozzles. Nozzles meant to provide air currents of varying velocities and temperature, with odor. Being a wearable device, Telesphere Mask highly resembles to the modern head mounted VR systems. However, it does not provide any motion tracking ability. Although Heilig actually build the device, he focused on a more advanced system. Sensorama, patented in 1962, was a device roughly equivalent in size to a video arcade cabinet, with a housing that holds a hood to fit the head of the observer, for viewing projected stereographic images through an optical setup. The hood also contains audio equipment and a breeze is directed toward to hood to enhance multisensory experience. Heilig created five films for Sensorama, a bicycle ride, a ride of a dune buggy, a helicopter ride over Century City, and a dance by a belly dancer, and a motorcycle ride in

New York city, which includes a vibrating seat, rush of air through observer's head with odors alongside the riding path. As this was the first olfactory stimulus embedded within an immersive technology, computer controlled olfactory interfaces were not available until 1993 (Youngblut et al. 1996). Heilig had the vision on the Sensorama's potential in education, training, and marketing but it was a commercial failure and the only instance of it was employed as an arcade console (Bown et al. 2017; Garner 2018). In the mid-1960s, he extended the idea to a multiviewer theater concept patented as the Experience Theater in 1969.

The Modern Age

As there are numerous developments in VR during modern era, these are given as sections instead of chronological order.

Head Mounted Displays

Built by Charles Comeau and James Bryan in 1961, The Headsight was a remote surveillance device that attaches a video camera to a head mounted display. It was not intended as an immersive virtual reality technology. For its motion tracking capabilities it is credited as a milestone in history of virtual reality, since it uses magnetometers to track head movements of the user to control the attached camera (Jerald 2015; Bown et al. 2017; Garner 2018).

In 1967, a civil and military helicopter manufacturing company tested a head-mounted display (HMD) that showed video from a servo-controlled infrared camera mounted beneath the helicopter. The camera motion is synchronized with pilot's head, both augmenting his night vision and providing a level of immersion sufficient for the pilot to equate his field of vision with the images from the camera (Fabri et al. 2008).

A technical report of a project in Wright-Patterson Air Force Base dated to 1969 is publicly available about the design of a helmet mounted display for US military pilots (Heard et al. 1969).

Ivan E. Sutherland envisioned a computer controlled virtual environment that emulates real-life physics in his classical article "The Ultimate Display" (Sutherland 1965). In 1968, Sutherland demonstrated his ideas with a prototype named "Sword of Damocles," a head mounted 3D display that is capable of presenting computer generated images to the user with a perspective image which changes as user moves. System employed special spectacles containing two miniature cathode ray tubes for stereoscopic vision; two head position sensors, one mechanical and the other ultrasonic, to measure the position of the user's head. The name "Sword of Damocles" comes from the mechanical head positioning sensor, a mechanical arm hanging from the ceiling. It is rather heavy and uncomfortable to use, and the ultrasonic solution was designed as an alternative. The display system was an augmented reality apparatus rather than a virtual reality device, since the images on cathode ray tube displays are reflected on half-silvered mirrors which allow user to see real-world objects in the room simultaneously. The images viewed by the user are transparent "wire frame" line drawings, due to the computational costs of rendering solid objects in real time. Although the objects viewed by the users are quite simple as a cubical room, Sutherland (1968) reports favorable response of users to good stereographic vision.

The origin of the contemporary VR HMD is based on the design of Drs. Mike McGreevy and Jim Humphries at NASA Ames Research Center. The system is called VIVED (Virtual Visual Environment Display), which later evolved into VIEW (Virtual Interactive Environment Workstation) as a general-purpose, multisensory, personal simulator and telepresence device, configured with head and hand tracking, monochrome wide field-of-view stereo head-mounted displays, speech recognition, 3D audio output, and a tracked and instrumented glove (Fisher et al. 1987) and has encouraged several American companies to develop related commercial products (Mcgreevy 1991).

An alternative to HMD's were boom-mounted displays, a stereoscopic binocular displays attached to a multilink arm. While the arms purpose was tracking the motion of user, it also helps to balance the display. Another advantage of this kind of setup is that suitability for turn-taking use for multiple people, i.e., when a user releases the

device, another person can take place and continue to view the virtual environment from the same perspective. Sutherland's Sword of Damocles was built around the same principle, while several boom-mounted displays were available as commercial products in 1990s (Youngblut et al. 1996).

Flight Simulators

The history of the mechanical flight simulators can be dated back to 1910, but the foundations of modern day flight simulation were based on Edwin Link's work (Allerton 2009). Based on the simulator technologies developed by aviation industry, several end-user motion chairs, predominantly intended for use in VE entertainment applications, became available in 1990s (Youngblut et al. 1996). However, Link's design was a motion simulator which did not include any external visual scene. Early visual systems were based on actual physical models, or pictures, such as the German bombers were trained in WWII, in which a continuous picture of a ground scene was rolled under the trainee who looked through the sight from a similar position to that in the actual bomber. Later, a miniature model of a scene around an airport was used over which a video camera traveled based on the aircraft's position as calculated by the flight model (Lawn 1998). The first computer image generation systems for flight simulation is developed for space program (Rolfe and Staples 1988). A version that is commercially available for civil aviation companies, Vital (Virtual Image Takeoff and Landing) was developed in 1969 as a laboratory prototype. The next version, Vital II, was approved by FAA and installed on a 737 simulator in 1972. Vital devices were only capable of visualizing lightpoints (Warwick 1987). Trainees see a night-like view of the landing scene at simulator's front windows, through a pair of cathode ray tube monitors. The VCASS (Visually Coupled Airborne Systems Simulator) was also an advanced flight simulator training of fighter pilots (U.S. Congress, Office of Technology Assessment 1994). Trainees wore a HMD that reflects the out of the window view. Thomas A. Furness, who worked as a scientist in the Wright-Patterson Air Force Base in 1970s, states that their efforts were also concentrated on design of virtual cockpits with very wide field of vision. In September 1981, their work lead to a virtual cockpit system with 120° of view on the horizontal (Carlson 2017).

Input Devices: Data Gloves, 6DOF Input, and Locomotion Systems

In 1976, Thomas DeFanti and Daniel Sandin developed an inexpensive, lightweight glove to monitor hand movements. Based on an idea of their colleague in Electronic Visualization Laboratory, Richard Sayre, the glow is named as Sayre Glove. Later in early 1980, MIT Architecture Machine Group used a camera-based LED system to track body and limb position for real-time computer graphics animation, termed "scripting-by-enactment." The method was intended as a body motion tracking system, which can be also employed for hand tracking. In 1983, Gary Grimes designed a glove, a specially tailored cloth for data entry using alphabet of hand signs with numerous touch, bend, and inertial sensors sewn on the glove. In 1987, the team of Thomas Zimmerman developed the Data Glove that uses fiber-optic wires and magnetic position tracking. Commercialization of the product led to a widespread use in research organizations, and inspired a commercial gaming glove that is manufactured in 1989 (Sturman and Zeltzer 1994).

As an alternative to relatively expensive gloves, 6DOF (six degrees of freedom) input devices were developed. In 1983, John Hilton sets out to develop a "3D force sensing joystick" for computer aided design applications while at the University of Sydney, Australia, and developed first prototype of Spaceball, which would lead to a line of products named as spacemice (spacemice.org 2016). Spacemice devices have a puck or ball that can be moved along X, Y, and Z axis as well as being twisted rotationally on each of those axis to roll, pitch, and yaw the 3D objects. An alternative input device type is flying mouse, or bat, originally developed by Ware and Jessome (1988).

Another type of input devices are locomotion interfaces that allow users to walk in the virtual environment. These type of interfaces appeared as

treadmills, sliding shoes, and foot pads, as well as some efforts to simulate walking with use of robotic tiles (Iwata 2013).

An early example of sliding shoes approach is Iwata's "harness and roller skate" design in 1989, in which the walker is fixed to the framework of the system by a harness and a pair of roller skate equipped with four casters which enables two-dimensional motion as the motion of the feet was detected by an ultrasonic range detector. The system evolved into "Virtual Perambulator," which employs touch sensor equipped rubber sandals with low friction film located at the middle of the sole (Iwata and Fuji 1996). Slater et al. (1995) used a method that does not require an additional hardware, by employing a neural network algorithm for analysis of the stream of coordinates from the HMD, to determine whether or not the participant is walking on the spot.

One of the antecedent locomotion treadmills were designed by James Lipscomb for the Walkthrough Project (Brooks 1987) in 1986, which uses a nonmotorized treadmill and bicycle handles. Since directionality is acquired through bicycle handles, the system was not an omni-directional treadmill. Within US Army Dismounted Infantry Training Program which began in 1992 (Singer et al. 1998; Knerr 2000), a unicycle-like pedaling system was developed in 1994, called Uniport. Uniport is the earliest example of foot pad approach in virtual locomotion, followed by the OSIRIS in 1995, which utilizes a stair stepper device as same as that used in athletic gyms. Uniport is replaced with Treadport in 1995, which is based on a unidirectional treadmill. Darken et al.'s (1997) omni-directional treadmill is a more advanced system, employing two layers of belts controlled by servo motors. The top belt comprised of an array of freely rotating rollers lies atop a second, orthogonally oriented belt also comprised of rollers. A tracking arm detects user's position. Another device within the treadmill approach, Virtusphere, utilizes a human-sized hamster ball. Built in 2006, Virtusphere is a ten-foot hollow sphere, which is placed on a special platform that allows the sphere to rotate freely in any direction according to the user's steps. User is able to walk and run inside the sphere, viewing the virtual environment through the head-mounted display (Medina et al. 2008). Circulafloor (Iwata et al. 2005) simulates an infinite surface by the circulation of a set of omnidirectional movable tiles. Each computer controlled tile move in the opposite direction of the walker's measured direction, canceling the motion of the step and fixing the walker's position. Currently, the locomotion devices have not become an affordable consumer product but there are several companies providing turn-key solutions for industry, academia, and business.

Mirror Worlds

Mirror worlds or projected realities provide a second-person experience in which the viewer is represented by her image taken by a video camera and merged into the virtual environment, and the computer processes the users' images to extract features such as their positions, movements, or the number of fingers raised (McLellan 2004). Computer artist Myron Krueger's efforts in combining interactive arts with VR were started in 1969, and led to Videoplace system in 1974 which is the earliest example of mirror worlds. The system employs video-based motion tracking to analyze the relationship between the user's image and the computer-generated objects and combines both on a projection display (Krueger and Wilson 1985). It can be used as a telepresence artifact for two users interacting with each other through the computer generated graphics.

Another early mirror world system dated back to 1986 is the Mandala VR System developed by a group of Canadian performance artists and commercialized as a product. The system employs a video camera that implements the captured video of the user into a computer generated environment or a previously taken video that is controlled by computer. There were several applications of the system including games and educational museum interactions (Wyshynski and Vincent 1993).

Virtual Projection and Virtual Spaces

In 1992, a research group in Electronic Visualization Laboratory and the School of Art and Design at the University of Illinois at Chicago introduced the concept of a room whose walls, ceiling, and

floor surround a viewer with projected images. The system they built had four screens, three walls, and a floor. It was named as CAVE (CAVE Automatic Virtual Environment), with a recursive acronym, in reminiscent of Plato's allegory of the cave (Cruz-Neira et al. 1992). Several CAVE systems were built around the world, mostly in research institutions to be used as a virtual environment, a virtual prototyping platform, and for visualizing scientific 3D spatial datasets.

Some examples are the CAVE's in Ars Electronica Center in Linz, Austria, which was the first to be installed outside the USA in 1996 (Kuka et al. 2009) and the world's first six-screen CAVE in Center for Parallel Computers at the Royal Institute of Technology in Stockholm, built in 1998 (Ihrén and Frisch 1999).

The advantages of CAVE environments over HMD displays is that multiple users can see each other in the CAVE at the same time, wearing shutter glasses instead of heavy helmets. System usually runs on a cluster of networked computers. Computers generate a pair of images following each other, one for each eye of the user, synchronized with shutter glasses. As a result, images seen by the user is three dimensional, as the objects are floating in the room. CAVE systems employ a motion tracking technology to locate the user in the room, besides interaction devices such as data gloves, joysticks, or wands (Manjrekar et al. 2014).

Consumer VR

In 1990s, VR systems became commercialized for consumers in entertainment industry. A leading attempt was committed by Jonathan D. Waldern (1992). Some of these systems that aimed to be commercialized as consumer products could not progress the prototype stage and failed to reach consumers, while other were commercial failures due to the conflict in users' high expectations and device's functionality and reality (Garner 2018). According to Stone (2008) "commercial naivety on the part of VR companies, significant failures to deliver meaningful and usable intellectual property on the part of so called academic 'centers of excellence,' expensive and unreliable hardware, an absence of case studies with cost-benefit analyses and a widespread absence of attention to the requirements and limitations of the end users" were factors that affected the development consumer level VR systems.

The first decade of the twenty-first century is described as the "VR winter" (Furness 2014). There was little mainstream media attention given to VR from 2000 to 2012, while there were no consumer level VR products. By 2012, ignited by a kickstarter project, companies ranging from start-ups to the Fortune 500 began to see the value of VR and started providing resources for VR development (Jerald 2015).

H

Cross-References

- Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology
- Locomotion in Virtual Reality Video Games
- Natural Walking in Virtual Reality
- Presence and Immersion in Virtual Reality
- Redirected Walking
- Virtual Hand Metaphor in Virtual Reality
- Virtual Pointing Metaphor in Virtual Reality
- Virtual Reality: A Model for Understanding Immersive Computing

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HMD: Head-Mounted Display

▶ Virtual Reality Applications in Education

Hologram

▶ Holography as an Architectural Decoration

Holographic Augmented Reality

▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums

Holographic Filmmaking

▶ Tabletop Storytelling
▶ Volumetric Filmmaking

Holography

▶ Holography as an Architectural Decoration
▶ Mixed Reality and Immersive Data Visualization

Holography as an Architectural Decoration

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Synonyms

Architectural decoration; Dichromate gelatin (DCG); Display holography; Hologram; Holography; Multicolor rainbow hologram; Rainbow hologram; Silver halide

Definition

Holography as an architectural decoration is an application of holography to the everyday living space of a building.

Introduction

Applications of holography have been developed and implemented in many fields; display holography is the most important and exciting application (Ishii 2006b). Various types of holograms exist, each of which has its own unique color or luster characteristics; some examples are reflection, laser transmission, white light transmission (rainbow), silver halide, and dichromate gelatin (DCG) holograms. In particular, the DCG reflection hologram exhibits certain favorable characteristics such as a metallic luster or pearl color. The white light transmission (rainbow) hologram is particularly impressive because of the way it displays the colors of the light (Ishii and Tsujiuchi 2008).

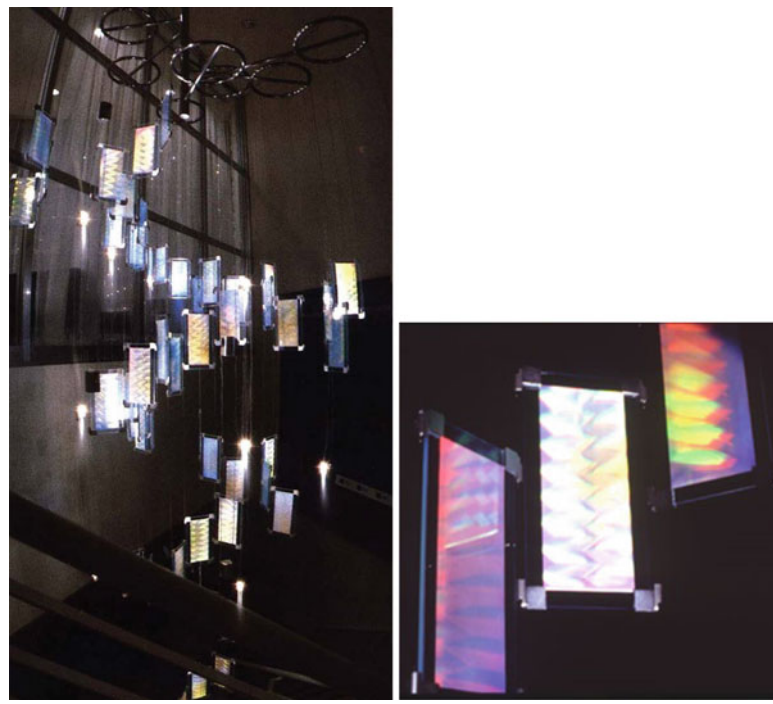
Various methods exist in which holograms are used as raw materials. Holograms are used in sculptural decorations as three-dimensional objects, atrium decorations, holography chandeliers, wall decorations, and in the staging of indoor prismatic displays of sunlight using holography grating.

This entry describes various attempts to bring the attractive, decorative applications of display holography into architectural spaces (Ishii 2007).

Shaw Cases

Holography Chandeliers

The work (Fig. 1) was installed in the stairwell of a pavilion building at the Science Exposition, which was held in 1985 in Japan. DCG holograms and low-voltage miniature halogen lamps were assembled together, which formed a holography chandelier.



Holography as an Architectural Decoration, Fig. 1 DCG reflection type of hologram

Sculptural Object

The case (Fig. 2) is installed in an entrance and consists of multiple DCG holograms, stainless steel poles, and a black granite base. Around the object's circumference, beams of light which are transmitted and/or are reflected from the hologram intersect. The use of the hologram in the design of the space has a significant influence on the surrounding environment. Its influence is especially noticeable at night when passing pedestrians can enjoy the object's brilliant effect in the entrance of the office building.

Holography as an Architectural Decoration, Fig. 2 Sculptural object in an entrance, 270 cm × 200 cm

Atrium Decoration in Public Space

Multiple DCG holograms and 10 large dichroic mirrors were combined and installed in a skylight window in 1997 at the public Health and Welfare Center of Japan. This demonstrates the combination of vivid color interference and holographic image (Ishii 2007). The appearance of the holograms and colors change constantly, depending on variance of ambient lighting conditions which is caused by factors such as weather and time (Fig. 3).

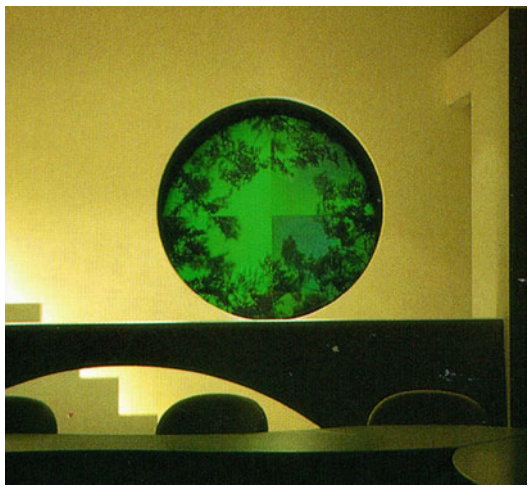
Wall Decoration

The works (Figs. 4 and 5) were finished in the shape of a mural painting. A silver halide reflection hologram with a diameter of 160 cm (Fig. 6) is installed in the basement (Ishii 1993). The reconstruction of the holographic image is enabled by guiding sunlight through optical fibers that stretch from the roof of the building to the basement (Ishii 2006a). Staff in the building are

Holography as an Architectural Decoration, Fig. 3 Atrium decoration in a public space

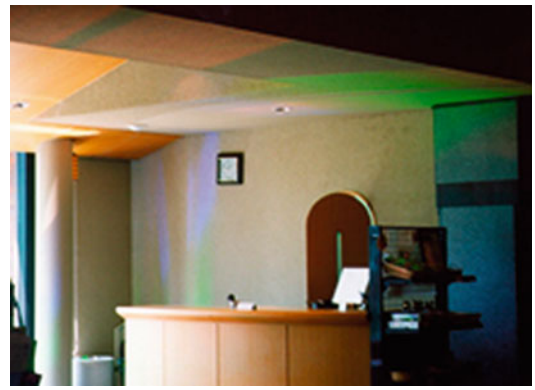
Holography as an Architectural Decoration, Fig. 4 DCG reflection hologram, 150 cm × 240 cm

Holography as an Architectural Decoration, Fig. 5 Entrance of the residential building



Holography as an Architectural Decoration, Fig. 6 Large format silver halide holograms reconstructed from sunlight

Holography as an Architectural Decoration, Fig. 7 On the ceiling of an entrance hall



Holography as an Architectural Decoration, Fig. 8 At a cafeteria

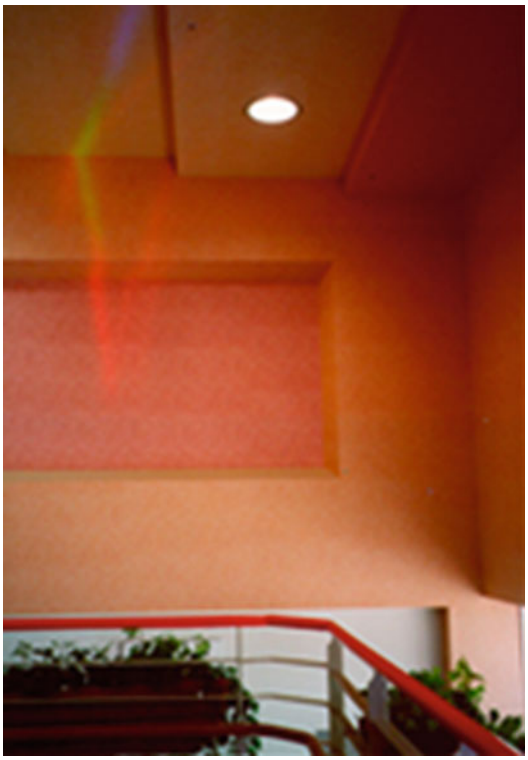
aware of the weather outside without moving from their seat.

Rainbow Production

When sunlight hits the grating installed in the crosspiece of a glass window, the diffracted light produces a rainbow color on a ceiling or wall (Figs. 7, 8, and 9). The rainbow moves across various surfaces with the movement of the sun. The sunlight's production of the rainbow carries brightness and peacefulness into an everyday living space. Holography is the easiest way to bring light of the sun inside a space (Ishii 2007).

Application for Large Format Multicolor Rainbow Holograms

Three large format multicolor rainbow holograms (Fig. 10b) were installed in a large-scale construction space (Fig. 10a) in 2003. Film holograms are laminated between two pieces of glass. Behind the holograms, a flat vessel containing water and with mirrors on its bottom is situated on the floor. The device produces ripples on the surface of the water that causes water droplets to fall from the top. The lights used for hologram reconstruction reflect from the mirrors under the water, adding dynamic movement and imparting a sense of vividness to the virtual image.

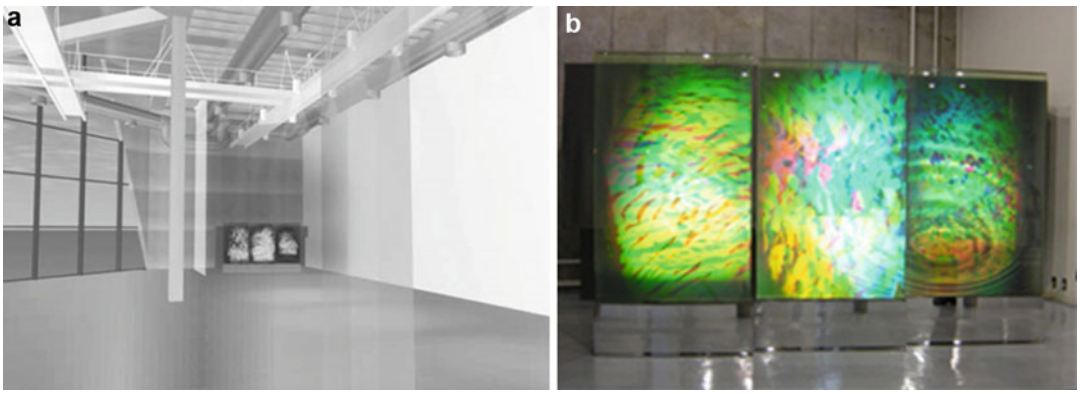


Holography as an Architectural Decoration, Fig. 9 Dining room of a care home for the elderly

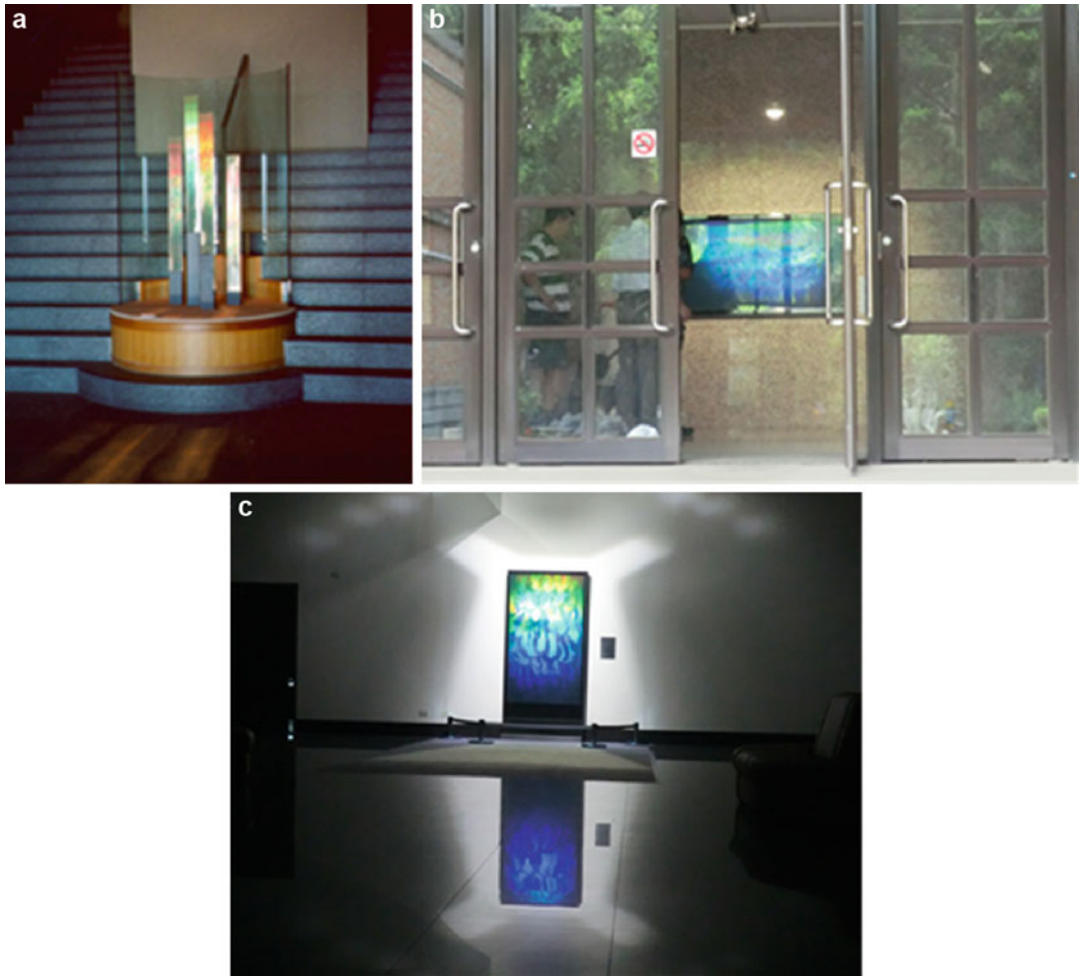
The transmission hologram requires a large area behind the hologram for lighting. At this point, the type of reflection is easier to manipulate than the type of transmission. In the following cases (Fig. 11a–c), multicolor rainbow holograms were installed and are dependent on the quality of their reflection, which is produced by mirrors. The works in Fig. 11b, c are installed in Taiwan.

Conclusion

When a hologram is likened to a painting, a tile, or a pottery plate, it can hold great potential as a new material for wall surface ornamentation. The wonderful and attractive effect created by the holograms cannot be realized with any other materials currently used in everyday living



Holography as an Architectural Decoration, Fig. 10 (**a**) At Tokyo Institute of Technology. (**b**) Multicolor transmission hologram with water ripple, 210 cm(h) × 300 cm(w) × 250 cm(d)



Holography as an Architectural Decoration, Fig. 11 Multicolor rainbow hologram with a mirror. (**a**) 110 cm × 10 cm × 4 cm. (**b**) 70 cm × 140 cm. (**c**) 230 cm × 110 cm

space. When a space is designed to accommodate the use of a hologram, it has a significant influence on its surrounding environment and produces brilliant, delightful, and comfortable spaces.

Cross-References

- ▶ Image Quality Evaluation of a Computer-Generated Phase Hologram
- ▶ Mixed Reality
- ▶ Substitutional Reality

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Holography, History of

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Synonyms

Diffraction microscopy; Holoscopy; Three-dimensional picture; Wavefront reconstruction microscopy

Definition

The use of illuminated light waves to create three-dimensional photographic representations of objects. Typically recorded on a photographic plate or film with a pattern of interference formed by split laser beams that scatter light and create the appearance of a three-dimensional shape once interacted with by light.

Introduction

The history of holographic technology begins hundreds of years ago in the inspiration of the past. Carried forward to each generation by strategic people, the total history of holographics is challenging to capture concisely. Below is an account of important people, pivotal moments, and critical inventions that brought us to our holographic technology of today.

History of Holographics

Holographics has a forebearer in the concept of "Pepper's Ghost." Inspired by the 1584 research of Italian scientist Giambattista della Porta, the inventor of the camera obscura, Henry Dircks experimented with bouncing images off of plate glass and created Dircksian Phantasmagoria, which he presented to the Association for the Advancement of Science in 1858 (Howard 2015). Dircks tried to sell his effect to theaters, but with no luck. It was a few years later in 1862 that John Henry Pepper modified the setup and projected ghosts for Dickens' *The Haunted Man*, and while he tried to give proper credit to Dircksian, it became renowned as "Pepper's Ghost." This would turn up at fairgrounds, haunted houses, magic shows, and any venue seeking to add flair until the technology modernized (Howard 2015).

Holography is a now familiar technology from its once obscure background. Derived from the Greek words holos, meaning "whole," and graphe, meaning "something written," it was coined in 1947 by British scientist Dennis Gabor while working on improving the resolution of an electron microscope. After learning of Gabriel Lippmann's work at the young age of 15, Gabor became inspired to study physics. Lippmann developed a theory of using light interference to capture color photography decades prior in 1886, eventually creating perfect color photographs to the Academy of Sciences in 1893 and publishing his full theory in 1894. He won a Nobel Prize for his work in 1908 and later became an adviser at the Physics Department at the Sorbonne, where he introduced Marie Sklodowska to her future partner and scientific genius Pierre Curie (History of Holography 2016).

Learning of this research, Dennis Gabor became inspired. But his story comes from a time of strife. He, as Lippmann, was also Jewish. He relocated to England to escape religious persecution at the hands of the Nazis in 1933 (History of Holography 2016). It was then that he moved to Thomson-Houston Research Laboratories in Britain. It was during his stay there that he developed the theory of holography, but due to technical infeasibility of the concept at the time, it would be another 20 years before the technology that we know as holography was able to come to fruition. He was attempting to improve the resolution of the electron microscope to be capable of seeing singular atoms, but came upon his own theory of wavefront reconstruction, soon to be called holography. What was required would be a powerful form of

light, which came in the 1960s with the invention of the laser. This allowed for the intense, coherent light necessary to construct holograms.

Holographics represents another trend for humanity, our ability for many of us to stumble upon a similar technology at the same time. While not knowing of Gabor's work, a Russian in the former Soviet Union by the name of Yuri Denisyuk became inspired by the very man that inspired Dennis Gabor, Gabriel Lippmann. After reading of Lippmann's work, he began to experiment in 1958 using a highly filtered mercury discharge tube, as there were no lasers yet. His work was published in 1962 to lackluster support. It wasn't until a visiting delegation of American scientist requested to meet with him that he saw his own esteem and fortunes rise.

Emmett Leith is another individual that followed a similar hunch like Gabor and Denisyuk. At the relatively young age of 25, he began researching highly classified works at the University of Michigan's Willow Run Laboratories in 1952. He was set to work to study synthetic-aperture radar (SAR). The army desired high-quality imaging radar system, but without further innovation in the field, then the antenna was projected to be so large that no airplane could carry it. They sought to create a synthetic antenna that had high-powered capability because it processed image data like a hologram – within small pieces over transmitted pulses. By 1957, Leith's new method was ready to be tested. After eight flights yielded no images, the critics seemed validated in their doubts of such a technology; however, on the ninth flight, the terrain was beautifully captured and the SAR system became famous (Emmett Leith).

It was in the 1960s that Leith turned toward the work of Dennis Gabor, realizing that there was more interesting research to be conducted. Gabor's work produced fuzzy images that also contained twin images, and the doubling of images was deemed unsolvable. Leith approached Juris Upatnieks, whom was not originally impressed by the work and recently joined the facility but become convinced after reading Gabor's experiment in *Principles of Optics* by Born and Wolf (1959).

Upatnieks had fled the Soviet occupation of Latvia with his parents, seeking asylum in Germany, and eventually emigrating to the United States (Emmet Leith and Juris Upatnieks Co-Inventors of Holography). He attended high school in Ohio, and after studying Electrical Engineering at the University of Akron, he received his Bachelor's degree in 1960 and began conducting research at the Michigan facility. What this pair would create together would cement their hands in the creation of modernized holographics, as they solved the twin image issue and greatly improved the technology. Even Gabor himself would mention Leith and Upatnieks in his 1971 Nobel Prize speech, stating that their success "was due not only to the laser, but to the long theoretical preparation of Emmett Leith, which started in 1955. . . This was in fact two-dimensional holography with electro-magnetic waves. . . Their results were brilliant" (Emmett Leith).

Like other technologies, the 1960s and 1970s were a time of true maturation. In 1965, Robert Powell and Karl Stetson published a paper on holographics interferometry, which proved useful for nondestructive testing of materials, fluid flow analysis, and quality control. Larry Siebert of the Conductron Corporation utilized a pulsed laser to create the first hologram of a person in 1967. This was instrumental in the early days of commercial display holography. Unfortunately, a recession in the early 1970s forced the company to close, shutting the door on a potentially huge market.

The late 1960s saw Stephen Benton's invention of white-light transmission holography while researching holographic television for Polaroid Research Development (Sergey). It was significant because it made the mass production of holograms possible by stamping the interference patterns onto plastic. These holograms could be duplicated millions of times over for a few cents apiece. This created embossed holograms that are now utilized by publishing, advertising, and many other industries.

Lloyd Cross combined white-light transmission holography with more conventional cinematography processes to create more realistic illusions. One of the most famous is a series of photographs called "Kiss II" in 1974, which was made from approximately 360 frames and shows

an image of a woman named Pam Brazier blowing a kiss and winking at the viewer as they walk by (History). He would later create Multiplex Company that produced hundreds of images using his technique.

The field of holography was divided into several camps. There were researches, artists, and artisans. In 1972, Tung Jeong began offering summer workshops for non-physicists at Lake Forest College in Illinois. This introduced a new medium for expression for artists that many ran with. Artists like Salvador Dali utilized holographic technology in exhibitions, such as at the Knoedler Gallery in New York. Work like his and others contributed toward the mainstreaming of this technology, as more of the public was introduced to it.

Through the next few decades until the millennia, there was the development and application of the technology across different spaces. The 1980s saw more integration of the technology to familiar items. In 1983, MasterCard International, Inc. was the first to use hologram technology in their banking security (History). It was deemed the largest distribution of holographic technology at that time. It was in March of 1984 that holographic technology made its way onto the cover of the National Geographic (volume 165, Number 3), with nearly 11 million holograms being carried throughout the world (History). In 1997, German inventor Uwe Maass created a roll up, transportable technology that enabled a new type of holographs that he deemed "eyeliner." This technique was modernized and utilized by a company called Zebra Imaging. The army utilized the technology in 2006 to have field maps that were 2 × 3 ft and could have a light shined on them which reveal a hologram of the terrain before them. It would show the steepness of the topography and where they might be vulnerable to ambush. The three- dimensional aspects of the new maps were a hit, and over 14,000 holographic maps were utilized by American troops in Iraq and Afghanistan over the next decade (Howard 2015).

Some might remember the 2005 concert where Tupac was presented on stage, while some may consider this a hologram technology, it was actually a twenty-first-century application of Pepper's Ghost. A custom-developed foil was utilized in the technique to create more realistic images. Tupac is not the only artist to be brought to life using this type of technology. The cartoon band by the name of the Gorillaz has long experimented with the concept, but due to technical issues, hologram-based concerts were still a challenge to tackle, and it took several more years before we were able to sit in a truly hologram-like experience.

In 2014, Uwe Maass came into the limelight again. Forming a venture with his peers, he created Hologram USA and MDH Musion, both of which are doing amazing things in the field of holographics. One example of the impressive sway this technology can hold comes from Narendra Modi, whom entered the race for Prime Minister of India. With low polling numbers, he hired MDH Musion and began delivering speeches simultaneously at hundreds of rallies across 1400 locations – reaching an estimated 14 million additional voters. His numbers went from a low 34% to 53% and won him the election (Howard 2015).

The 2016 live performance by Callie and Marie at Niconico Tokaigi, Japan (Splatoon 2016), and the 2018 Hatsune Miku Concert in Los Angeles (Hatsune Miku Concert 2018) have both demonstrated new advances in holography where concertgoers were able to enjoy a hologram-like experience.

The holography market is projected to hit $3.57 billion by 2020 (Holographic Display Market). With applications across entertainment, military operations, financial markets, politics, work, and home use, there is an appetite for the technology. After many decades it took to bring it to full actualization, the twenty-first-century evolution of the technology may finally bring what we have been only able to speculate in science fiction novels to life.

Cross-References

▶ Hologram
▶ Holography

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Holoscopy

▶ Holography, History of

Horror Game

▶ Five Nights at Freddy's, a Point and Click Horror Game

HRI AR

▶ Augmented Reality for Human-Robot Interaction in Industry

HRIR

▶ User Acoustics with Head-Related Transfer Functions

HRTF

▶ User Acoustics with Head-Related Transfer Functions

HUD (Heads-Up Display)

▶ Game Interface: Influence of Diegese Theory on the User Experience

Human Detection

▶ Deep Learning Algorithms for 3D Reconstruction

Human Factors

▶ Cognitive Psychology Applied to User Experience in Video Games

Human Interaction in Machine Learning (ML) for Healthcare

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Synonyms

Artificial intelligence; Deep learning; Machine learning; Neural networks

Definitions

The field of artificial intelligence (AI) is the development of machines that can perform human-like tasks, such as reasoning, perception, and decision-making. Machine learning (ML) is a subfield of AI that allows machines to learn from data without the need for explicit programming. Neural networks (NN) and deep learning (DL) take this a step further by enabling machines to learn from complex and unstructured data like speech, images, and natural language, and use that data to make predictions. NN is an ML algorithm that imitates the structure and function of the human brain, consisting of interconnected neurons that process information. DL is a specific subset of NN that utilizes multiple layers of artificial neurons to enable machines to learn and make predictions from vast amounts of data. Human-computer interaction (HCI) studies how people interact with digital technologies and designs interfaces and interactions that are user-friendly and intuitive. This is essential in creating effective and efficient AI and ML systems that enhance human-computer interactions. Together, these technologies and approaches work in harmony to create intelligent machines and improve the user experience.

What Is Machine Learning (ML)?

Machine learning (ML) is a type of artificial intelligence (AI) technologies that allows software applications to become more accurate at predicting outcomes. There are vast opportunities that ML gives, some being used right now, others yet to come. As ML becomes pervasive in our day-to-day applications, most systems nowadays involve ML. ML led to better outcomes and improved efficiency in most scenarios. In this context, systems implement and utilize different ML and AI algorithms. The nature of ML implementation involves systems having a more significant than a typical role in obtaining, utilizing, and protecting data. ML models extract valuable features and insights from data to detect different activities in systems. Systems are now responsible for more advanced and expensive decisions.

Machine Learning (ML) in Healthcare

Due to the improvement in ML, the variety of applications for healthcare information systems has increased dramatically. This advancement has opened the door to many medical operations based on ML models. ML systems provide medical situational insights, quick medical reminders, and accurate medical forecasts (Koh and Tan 2005). Utilizing these cutting-edge technologies has accelerated the digitization of healthcare institutions, primarily driven by the need to improve medical processes. ML systems are now a tool that can supplement physicians' decision-making process, generate individualized and customized health management plans, predict the next health crisis, and develop personalized treatments that employ precision medicine (Chancellor et al. 2016).

In recent years, healthcare systems got involved in many AI and ML contexts, from monitoring things such as diabetes (Nasser et al. 2021) and cancer care (Onasanya and Elshakankiri 2021; Pradhan and Chawla 2020) for identifying different kinds of pathologies and chest x-rays or even in mental health as identifying depression

(Kumar et al. 2021). Healthcare systems now can predict and control any new infectious disease, e.g., COVID-19 (Mukherjee et al. 2021) or Monkeypox (Ahsan et al. 2022). As such, ML and AI in healthcare have shown to be very extensive in achieving a higher quality of service and patient health.

Interactive ML (I-ML)

Real-world uses of ML techniques have shown weaknesses that result in poor results and the need for improvement. ML algorithms require access to good-quality, unbiased, and complete training data to work optimally. In most cases, a lack of high-quality data leads to poor results. While ML techniques can provide exact and quite well solutions for well-structured problems, they are unsuccessful for nondeterministic polynomial time (NP)-hard and ill-conditioned problems. Humans are the only entities capable of explaining the limitations of ML approaches since humans are excellent at abstract thoughts and solving computationally complex problems. As such, one way to improve the performance of ML systems is through human involvement in the process. The mechanism through which humans and ML systems work together is known as interactive machine learning (I-ML). It is feasible to construct systems more quickly and effectively by merging human feedback with ML, and that leads to more precise system design and predictions that are more accurate. For example, Fails and Olsen established I-ML, showing its importance and promise (Fails and Olsen 2003). Moreover, in (Zerilli et al. 2019), Zerilli et al. discuss including individuals in decision-making. Humans and ML will need to work together in the future for many ML applications, no matter how well planned. Elish and Watkins observe that using an AI system to assist in identifying sepsis patients disrupted clinical operations and drove nurses to devise novel solutions to the problem (Elish and Watkins 2020). Nurses are responsible for integrating AI findings with established clinical diagnostic procedures. In (Nascimento et al. 2018), ML experts attempt to automate streetlights using ML. In many cases, humans outperform AI. To improve the design of automated streetlights, a human–AI interface using both human and ML techniques is presented. In a different case, the text is put into groups using ML, even though the initial data processing was done automatically (Yang et al. 2019). Humans are added to the loop if the first results are not good enough. Such issues show some limitations of ML, and that human understanding is the primary remedy. ML can deliver precise and accurate solutions to well-structured queries, but not too ambiguous ones while building complex new algorithms. When humans and ML techniques are combined, systems become more effective and exceptional, as humans are the most informed and possess abstract thought.

I-ML in Healthcare

Various research on human behavior for Al interactions has been published in the field of medical applications. Protein structure, genomic annotation, image analysis, and knowledge base population are healthcare problems still requiring human involvement. In some instances, many humans are necessary; in others, we need only a limited number of highly trained professionals in specific fields. For example, in (Caruana et al. 2006), ML and biochemists work to categorize low-level protein structures. They begin by clustering protein structures. After then, biochemists would discuss the data. Biochemists review the discoveries and apply new constraints for the next iteration. Clustering parameters are next changed to fit restrictions. In another study, experiments evaluate the I-ML "human-in-the-loop" technique, especially when it comes to opening the "black box" and letting a person alter and interact with an algorithm directly or indirectly (Holzinger et al. 2016). The research involves a framework for the traveling salesman problem that solves practical difficulties in health informatics, such as protein analysis. In (Holzinger 2016), a study identifies a problem by finding globally optimal protein threading, which checks if threading with a score less than or equal to K exists. This problem is categorized as NP-hard. Problems labeled as

NP-hard cannot be solved in polynomial time. One of the primary advantages of human interaction in ML is the ability to tackle NP-hard problems. Another study in (Holzinger 2016) discusses the k-anonymization problem of a record publication that cannot be identified from k other entities in the data. While the task of k-anonymization is similarly NP-hard, the suppression or generalization of attributes can measure the effectiveness of the outcome until each database row is identical to at least k−1 other row. Using generalization and suppression, an extension of the k-anonymity model maps any given record in the dataset to at least k others. A human best performs this.

Experts Within Healthcare I-ML

In I-ML applications, when the task is professional and complicated, we observe that humans with a higher domain expertise should be in the loop. With the help of domain experts, ML applications have coined a new term: HILML, or human-in-the-loop machine learning (Maadi et al. 2021). Generally speaking, for humans who collaborate with ML methods, the more expertise is, the better human–ML interaction outputs are achieved. Their assistance entails incorporating patient-specific information, treatment outcomes, and any additional repercussions associated with previous decisions made by the semi-automated system. In addition to assisting with pattern recognition and providing data from the outside, their assistance also includes giving external data. It is very beneficial to combine the specialized knowledge of medical professionals, such as physicians, and doctors, into intelligent healthcare systems through interactive ML, which is later strengthened by further data and expert knowledge. According to (Budd et al. 2019), there are two stages where medical professionals can help.

– Training phase: The training phase consists of inputs and predicted output pairs manually labeled by experts. Expert engagement is helpful in assisting ML when datasets are small or of poor quality. Hence, medical experts add new annotations to be used for model training. Moreover, experts fine-tune the model using the new recent annotated data until the ML algorithm is optimal. In the discipline of ML, "annotation" refers to labeling data to indicate the outcome you want the model to predict. In this context, we train a model with the new annotations, and the model then uses the latest data to increase its prediction accuracy. As such, we acquire more precise labels. This procedure, where experts feed data to the computer to assist future decisions, is known as supervised ML. The goal of training is to enable the algorithm to make correct decisions when presented with new data. Unlabeled datasets, on the other hand, are employed as unsupervised ML. Under these conditions, the algorithm is programmed to seek and define its own structure of unlabeled data. This part is referred to as a deep learning (DL) approach.

– Testing phase: Testing and evaluation from experts help in fixing wrong results. There are two kinds of wrong decisions: those in which the algorithm is uncertain and those in which the algorithm is certain, but the outcome is incorrect. To solve this problem, and after an ML model has been trained, experts evaluate model predictions and make changes to it to get the most accurate results for data. When experts are involved, automated predictions may need to be changed by hand in order to meet those criteria. A model must be capable of communicating with experts to provide meaningful interpretations of model predictions. This lets users take the best action when interacting with model outputs and decreases human uncertainty.

I-ML and Serious Games

Serious games are becoming increasingly important in the field of I-ML in healthcare as they offer a unique and efficient way to solve medical problems. By simulating real-world medical scenarios through games, medical professionals can assess their decision-making skills and improve their ability to diagnose and treat patients in a controlled and safe environment. I-ML uses serious games to provide healthcare professionals with

hands-on learning opportunities and the opportunity to apply their knowledge in a hands-on environment. In (Wang et al. 2016), a systematic review aims to assess the current state of research on the use of serious games in healthcare and provide an overview of such games' history and current usage. The authors further discuss potential benefits and challenges associated with using serious games in healthcare.

I-ML also uses computer graphics and data visualization to create virtual environments that enable medical professionals to visualize and interact with complex medical structures and processes. Additionally, serious games can provide real-time feedback and analytics by monitoring player performance. This allows you to identify and address improvements. This kind of feedback is extremely valuable to healthcare professionals as it supports ongoing skill development. A study explores the role of visual analytics in healthcare and provides a comprehensive overview of state of the art in the field (Preim and Lawonn 2020). It also covers various topics, including visualization techniques, interactive graphics, data-driven models, and decision support systems.

Games are a valuable tool in health education and can be used to educate patients about their health, provide tools for effective health management, and guide better health outcomes. They can be used for patient education, physician training, and medical scenario simulation. The benefits of using serious games in healthcare include improved knowledge retention, engagement, and decision-making (Cain and Piascik 2015). It has also been shown that it can educate patients about and improve health outcomes in the management of chronic diseases such as diabetes (Talley et al. 2019).

Prons and Cons of I-ML on Healthcare

In healthcare systems and society, the most critical tasks for I-ML are fostering trust and transparency. I-ML provides patients, clinics, hospitals, specialists, and everyone interested with transparency in its services. It is imperative that patients establish reliable connections with ML systems. For example, if a patient is told that an image led to a cancer diagnosis, they will undoubtedly want to know why. Moreover, ML systems can deliver more accurate assessments combined with the expert knowledge of healthcare professionals, particularly when using small or poor-quality healthcare datasets. This is done using the previous two roles mentioned, data labeling combined with consistent feedback on the algorithm's decisions.

On the downside, however, experts need to frequently annotate data during the learning phase and verify the decisions suggested by the ML model to ensure that it is the best decision regarding the risks imposed on patients. The process of data labeling and continuous feedback are time-consuming manual processes. Labeling requires experts to annotate and categorize complex images such as X-rays, CT scans, etc. Also, whenever experts are added, the cost of bringing doctors or other experts into the loop makes it costly. Nevertheless, if there were errors, it would result in a considerable increase in the cost. In practice, and to save costs, it is feasible to determine what confidence level is acceptable for the ML models involved. Confidence criteria can be lowered if wrong decisions do not have a negative impact, requiring less expert engagement and lowering the cost of interactive ML.

Discussion and Conclusion

Few studies have been completed on AI and human collaboration in healthcare, and new research is being conducted in this field (Bossen and Pine 2022). This indicates that there are still important considerations when attempting to incorporate ML into everyday life. More research is required to identify the when, where, and why of collaboration between humans and ML in healthcare systems. Together, ML and humans in healthcare may be incapable of making the best decisions. It has been proved that when ML incorporates information from various sources, it can surpass humans in decision-making in some scenarios (Liu et al. 2019). In addition, most studies evaluating ML's application in healthcare have

focused on improving the accuracy of medical workflows. ML is anticipated to impact healthcare administration as well drastically (Bossen and Pine 2022). Given the recognized limitations of both human reasoning and ML, it is still being determined whether doctors and ML systems can rely entirely on one another to make accurate decisions.

Researchers believe that human connection is essential for ML to succeed in gaining expert confidence in a healthcare context. To put this in perspective, most researchers do not come from a medical background, in striking contrast to medical practitioners. Interactions with medical professionals, whom each have their distinctive blend of knowledge, experience, and expertise, have the potential to improve ML systems. Following an analysis of the relevant research, combining ML with human input has the potential to enhance the delivery of healthcare. This entry highlights the potential reliability and precision of decisions generated by ML algorithms supported by the knowledge of medical experts.

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Human Tracking

▶ Locomotion and Human Tracking in Healthcare Robots

Human-Computer Interaction

▶ Cognitive Psychology Applied to User Experience in Video Games
▶ Emotion-Based 3D CG Character Behaviors
▶ Game Interface: Influence of Diegese Theory on the User Experience
▶ Gaming Control Using BCI
▶ Interactive Augmented Reality to Support Education
▶ Shadow Shooter: All-Around Game with e-Yumi 3D

Human–Computer Interaction

▶ Biosensing in Interactive Art: A User-Centered Taxonomy

Human-Computer Interface

▶ Shadow Shooter: All-Around Game with e-Yumi 3D

Humanness

▶ Uncanny Valley in Virtual Reality

Humanoid Avatar

▶ Deep Reinforcement Learning in Virtual Environments

Humanoid Robot

▶ Virtual Reality and Robotics

Hybrid Reality

▶ Substitutional Reality

Hypermedia Narrative as a Tool for Serious Games

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Synonyms

Interactive digital literature; Interactive multimedia narrative; (as a tool for) Applied game; Formative game; Game with a purpose; Games for change

Definition

Hypermedia refers to interactive multimedia in a nonlinear medium. It may include video, plain text, audio, graphics, and animation brought together using hyperlinks (links referring to data). A narrative is a story or report connecting events. It may include characters, time (duration and frequency), and a space where characters develop and perform actions. Hypermedia narrative is a tool to develop ideas, documents, and multimedia using digital tools.

A game is an activity with specific rules related to a physical or mental feeling of evasion of reality and enjoyment performed by one or several players who freely participate to solve a challenge. A video game is an interactive computer-based game using a user interface to provide feedback, which includes automatic processes and actions and hidden rules occurring in the computer. A serious game is a sort of game software developed with intentions going beyond entertainment. Games may integrate a story, game mechanics (rules of the game) and dynamics, technology, and arts (visuals and sound) to create a playability.

Hypermedia narrative as a tool for serious games refers to using it to impact the story of a game, affecting its mechanics and arts thorough the use of interactive technology to produce nonlinear playability. The idea is motivating emotions and using interactivity to make the player live those emotions with a purpose that goes beyond mere entertainment.

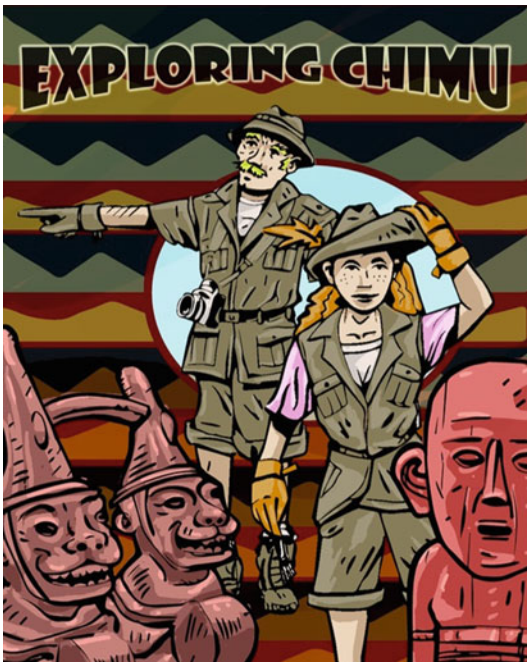
Introduction

Games favor knowledge acquisition and retention and force players to focus on solving problems. Their use brings benefits such as engagement, motivation, skills development, and learning. Serious games have been widely used and have gained the attention of researchers because they can capture players' enthusiasm while raising awareness of diverse subjects (Prakash and Rao 2015).

Hypermedia narrative allows the author and the reader to approach the creative process of a new story promoting a partnership which empowers the reader as a reader-author. Within this process, interactive stories, such as the ones used in games, are deconstructed and built again, while the meaning attributed to them and the degree of implication of the reader-authors are in continuous change. Space, time, personages, and actions conform the contents used by authors and reader-authors to construct an interactive speech (Prakash and Rao 2015).

Example

Hypermedia narrative can be used in contexts such as museography (museum methods of classification and display). The Exploring Chimú exhibit at the Museo de América in Madrid, Spain, was developed in four phases (Prakash and Rao 2015). The result was Exploring Chimú (Fig. 1), a serious game where the player is an archaeologist who finds a Chimú pyramid (the



Hypermedia Narrative as a Tool for Serious Games, Fig. 1 Exploring Chimú's promo

Tantalluc pyramid) in the ancient Peru (Navarro-Newball et al. 2016). The Chimú culture inhabited Northern Peru between 1000 and 1470 (Navarro-Newball et al. 2016).

Phase 1: Writing the Narrative Script

Hypermedia narrative was used to identify, analyze, and validate important visual and textual elements, points of nonlinear interaction, and potential technological solutions. An interdisciplinary team of artists, information scientists, archaeologists, designers, cultural managers, and computer scientists reunited to build a narrative script. Cultural managers coordinated the interaction among professionals. Archaeologists made sure that the script had historical rigor. Artists created 3D visual models for the script and 2D models for the user interface. Designers proposed the layout of the exhibit. Information scientists identified potential points of interaction within the narrative. Computer scientists validated the technical feasibility of the proposal. The interdisciplinary team served the interactive storyline in a way that the player (reader-author) feels the contents as his or her own (as coauthoring this story).

Phase 2: Developing the Interactive System

Hypermedia narrative was used to validate the user experience and the archaeological rigor of the prototypes iteratively provided by the developers. The team found that user interaction had to be simplified. Artists developed 3D and 2D models to be used in the video game, and computer scientists programmed it. The rest of the team and likely users helped in the continuous validation of the interactivity provided by a gesture sensor and the interactions performed by the players to achieve a good user experience model.

Phase 3: Production

Hypermedia narrative was used to validate the original narrative script developed in the first phase against the resulting serious game. It was an opportunity to perform the final user experience validation and to test the game's accessibility. The team found that the system lacked some audio output and that the sensor had to be adjusted to support people of different heights. This phase was oriented by the information and computer scientists.

Phase 4: Final Implementation

Hypermedia narrative was used to integrate the serious game within the museum environment coherently. The designer developed a layout including actual archaeological pieces related to the pieces shown within the game, thus, integrating the museum's real experience with the virtual one. The rest of the team validated the implementation.

Trends

Mobile technologies can provide portability that goes beyond the place where the actual interactive serious game has been deployed. Artificial intelligence can provide automated interactions, behaviors, contents, and evaluations adapted to the user or the context where the system is deployed. Mixed and virtual realities can provide usable and novel immersive interfaces that augment contents. Technology usage guided by hypermedia narrative supports the development of better and more immersive interactive storylines, augmenting knowledge and making it accessible in a noninvasive manner (Moreno Sánchez and Navarro Newball 2016).

For example, Towards Tantalluc (Prakash and Rao 2015) is a mobile application where the player is a Chimú native who builds the objects that are going to be taken to the Tantalluc pyramid. Once an object is built, the player must find it in the museum collection and have an augmented reality experience with it, using a mobile device. In this case, what mobile and mixed reality technologies do is to motivate the visitor to walk and observe the museum exhibit.

Conclusion

With hypermedia narrative, an interdisciplinary team where members must contribute in all phases

of the process actively considers technological trends and advances coherently to develop serious games creating interactive storylines that augment knowledge and make it accessible. Hypermedia narrative usage in an educational game for a museum was shown. It can be used in other kinds of serious games such as speech therapy games (Navarro-Newball et al. 2014) and environmental consciousness (Prakash and Rao 2015), among others.

Cross-References

- ▶ 3D Modelling Through Photogrammetry in Cultural Heritage
- ▶ Artificial Intelligence
- ▶ Augmented Reality
- ▶ Interaction
- ▶ Mixed Reality
- ▶ User Experience
- ▶ Virtual Reality

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Idle Game

► Incremental Games

ILD

► User Acoustics with Head-Related Transfer Functions

Image Captioning

► Automated Image Captioning for the Visually Impaired

Image Processing

► Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces
► Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications

Image Quality Assessment

► Image Quality Evaluation of a Computer-Generated Phase Hologram

Image Quality Evaluation of a Computer-Generated Phase Hologram

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Synonyms

Image quality assessment

Definition

Quality of reconstructed image from computer-generated phase hologram is evaluated objectively on its peak signal-to-noise ratio and brightness.

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Introduction

Hologram can record and reconstruct or playback an optical wavefront on the hologram plane. It uses interference between two waves, an object wave from the object to be recorded and a reference wave. The interference intensity pattern is recorded on a photosensitive material. Computer-generated hologram (CGH) simulates this optical phenomenon in a computer (Lohmann and Paris 1967). CGH is widely used to show not only for 2D images but also complex 3D images. Image quality of the reconstructed image from CGH is usually evaluated subjectively. For example, an observer compares two images and scores. Here shows basic research to evaluate reconstructed image quality of phase-type CGH objectively on its peak signal-to-noise ration and brightness (Yoshikawa and Yamaguchi 2015).

Computer-Generated Hologram

The Fourier hologram can be calculated with the Fourier transform of an original image. Figure 1a shows the image location in the input image plane for the Fourier transform, and Fig. 1b is a synthesized CGH. Figure 1c shows a numerically reconstructed image from the CGH. As one can see from Fig. 1c, the reconstructed image includes the desired image appeared as same position of the original image and the conjugate image that appears as the point symmetry to the center. The direct light (or non-diffracted light) is eliminated numerically in the figure, but it usually appears at the center and should be taken into account to evaluate image quality. The original image should be placed off-center not to overlap with the direct light and the conjugate image. Therefore, the original image is located center in vertical and right most side in horizontal. For the hologram calculation, the pixel value other than the original 2D image is set to zero. The random phase is multiplied to each pixel to make the reconstructed image diffusing and bright. Then 2D Fourier transform is applied to the transmittance distribution of $o(x, y)$ on the input image plane, and the result of $O(X,Y)$ represents the complex amplitude of the object beam on the hologram plane. If the reference beam is collimated and its direction is perpendicular to the hologram, the complex amplitude of the reference beam $R(X,Y)$ can be represented as the real-valued constant r. The total complex amplitude on the hologram plane is the interference of the object and reference beam, represented as $O(X,Y) + r$. The total intensity pattern

(a) 2D image location on an input image plane.

(b) Calculated CGH.

(c) A simulated reconstruction image from the Fourier hologram.

Image Quality Evaluation of a Computer-Generated Phase Hologram, Fig. 1 Image location and reconstructed image of the Fourier transform hologram. 2D image size $W = H = 120$ and the hologram size $N = 256$

$$I(X,Y) = |O(X,Y) + r|^2 = |O(X,Y)|^2 + r^2 + rO(X,Y) + rO^*(X,Y) = |O(X,Y)|^2 + r^2 + 2r\Re\{O(X,Y)\}, \quad (1)$$

is a real physical light distribution on the hologram, where $\Re\{C\}$ takes the real part of the complex number C and $C*$ means the conjugate of C. At the right most hand of the Eq. 1, the first term represents the object self-interference, and the second is the reference beam intensity. The third term is the interference of the object and the reference beams and contains holographic information.

Calculation Without the Object Self-Interference

In the CGH, it is quite easy to use only the interference term $2r\Re\{O(X,Y)\}$ of Eq. 1. This idea is proposed at very early stage of CGH research (Waters 1966). The interference part can be written as:

$$I_b(X,Y) = \Re\{O(X,Y)\}. \quad (2)$$

The normalization defined in Eq. 3 is applied to make final fringe intensity positive,

$$I_n(X,Y) = \frac{I_b(X,Y) - I_{\min}}{I_{\max} - I_{\min}}, \quad (3)$$

where $I_{\max}$ and $I_{\min}$ are the maximum and the minimum values of $I_b(X,Y)$, respectively.

Numerical Reconstruction of Phase Hologram

For reconstruction simulation, the complex amplitude transmittance $t(X,Y)$ of the transmission phase CGH is assumed as:

$$t(X,Y) = \exp[-i\Delta\phi I_n(X,Y)]. \quad (4)$$

Then $t(X,Y)$ is inverse Fourier transformed to obtain the reconstructed image. In the case of a sine-wave phase grating, the maximum diffraction efficiency of 33.8% is obtained at $\Delta\varphi = 0.59$. Therefore, this value is used unless denoted.

Diffraction Efficiency

The diffraction efficiency (DE) is defined as the ratio of the intensities of the reconstructed image and the illumination light. It gives the brightness of the reconstructed image. In the numerical experiments, the reconstructed image intensity is obtained by summing up all intensities in the reconstructed image area as same size and position of the original image in the input image plane.

Peak Signal-to-Noise Ratio

The peak signal-to-noise ratio (PSNR) is defined as the ratio of the maximum signal power and the noise power. The reconstructed image is extracted from numerically reconstructed image plane such as Fig. 1c and normalized to 8-bit grayscale image that has same mean intensity of the original image, and then the PSNR is calculated as:

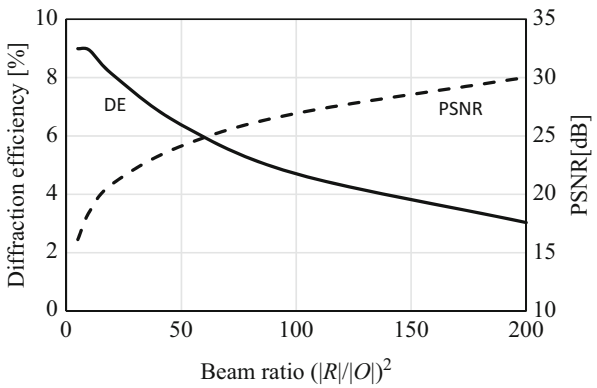

Image Quality Evaluation of a Computer-Generated Phase Hologram, Fig. 2 Diffraction efficiency and PSNR against beam ratio for transmission phase hologram. Solid lines show DE, and dashed lines show PSNR

$$\mathrm{PSNR} = 10\log_{10}\frac{255^2 WH}{\sum_{i=0}^{W-1}\sum_{j=0}^{H-1}[J(i,j)-K(i,j)]^2}\,[\mathrm{dB}], \tag{5}$$

where W and H are horizontal and vertical pixel numbers of the image and J and K are intensities of the original and the reconstructed image.

Numerical Experimental Results

Figure 2 shows DE (solid line) and PSNR (dashed line) of the rigorous calculation against the beam ratio (BR, defined as $|R|^2/|O|^2$). The DE of the phase hologram becomes over ten times larger than that of the amplitude hologram (Yoshikawa 2015). Since the object self-interference (OSI) term of $|O|$ in Eq. 1 causes noise on the reconstructed image, it is known that larger beam ratio gives better PSNR. However, DE becomes smaller with larger beam ratio. The hologram calculated without OSI as shown in Eq. 3 gives PSNR of 25.0 dB with DE of 8.8%, which achieves both low noise and bright image simultaneously.

Conclusion and Discussion

Image quality of phase CGH is evaluated objectively on the diffraction efficiency and the peak signal-to-noise ratio. For the transmission phase hologram, although it is obtained over ten times of diffraction efficiency against amplitude hologram (DE = 0.77%, PSNR = 38.9 dB), PSNR is not as good as that of the amplitude hologram. Since the evaluated hologram is very simple phase hologram, it is expected to evaluate other type of phase hologram.

Cross-References

► Holography as an Architectural Decoration

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Image-Based Modeling

► 3D Game Asset Generation of Historical Architecture Through Photogrammetry

Image-Guided Surgery

► Augmented Reality in Image-Guided Surgery

Imagineering Ceramic Pottery Using Computer Graphics

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Synonyms

Computer-aided design (CAD); Computer-aided industrial design (CAID); Three/Two dimensional (3D/2D) graphics; Virtual pottery (VP); Virtual/Augmented reality (VR/AR)

Definition

Imagineering in Virtual Pottery is to realize the artist's dream of creating intricate shapes.

Imagineering at the next level seeks realistic interaction with the shape digitally using devices that provide the touch and feel of real pottery in the virtual world. To push the boundary further in imagineering, the artist wants the virtual clay to be malleable and behave like real clay in capturing intricate shapes, and also it is printable. Ideally, imagineering in virtual pottery enables and demands bidirectional fluidity.

Introduction

Traditional pottery relies on the hand skills of an artist, the ceramic material and an understanding of the kiln and making process. This is further refined by a range of decorating, glazing, and firing techniques. The artist also uses techniques such as hand forming, throwing, and slip casting, among others. This article highlights how all of these techniques can be brought to the virtual world. Digital creative technologies are gaining maturity and now enable artists to reach greater heights. An example of imagineering that has come to fruition and fundamental to this article is sound shape modeling. Sound creates several detailed shapes when it interacts with clay and fluid. The artist would like to model those intricate shapes and patterns that are extremely difficult to create using the artist's hands.

This article focuses on virtual pottery modeling. The approach seamlessly captures the shape, interaction, and making in the artistic pottery process, albeit using digital creative tools. Computer graphics modeling over the past decades has shown a high demand for sophisticated realism of geometric shapes. Graphical shape modeling has found pervasive use in various fields, e.g., Arts, Medicine, Engineering, and many other fields. Digital technologies have also revealed a new path for contemporary art and creation. Today arts, science, and technology are united by a bridge of creativity, allowing cross-disciplinary fields to meet.

The impact of this bridge has created opportunities and challenges for a new innovative approach, enhancing and promoting existing experiences and outputs (Krasteva 2016). VR/AR painting and pottery making is the innovative beginning of advanced 3D modeling in art practice, opening the imagination to conquer realistic visual and physical real-world reality, to produce, share, and enhance skills. Clay based modeling is an ongoing trend for developers of 3D/AR/VR modeling to explore, expand, and develop. This method brings realistic deformation, representing real objects transformation, to the human visual concept that augments a more genuine and real visual appearance. Clay 3D modeling is a method that integrates digital deformation as simulation upon real geometric and physics data. It represents a 3D surface mesh sculpting with tools to push, pull, twist, inflate, surface relief, as well as a voxel-based geometry method to add/subtract.

Imagineering using computer graphics has not only enabled artists to visually interact with the creation of artistic objects, but also provide the essential link for fabrication to physicalize the artistic creations. This on the surface looks feasible but needs to grow in maturity to process and transform the visual form to physical form. This requires a detailed understanding of the processes in manufacturing and even more detailed understanding of the materials and their properties for ceramic fabrication.

Background

Virtual Deformable Shape Modeling in Fine Art

Virtual reality modeling is one of the cutting-edge creative technologies that support deformable shape modeling, using physical interaction data to enhance objects by color, depth, and deformation. One of the examples is volumetric modeling introduced by Kim et al. (2018). The authors demonstrated a high-resolution method of volumetric painting in virtual reality with high depth complexity. The technique consists of digital painting on 2D surfaces extended into 3D volumetric painting.

Ioana also examined another method using Tilt Brush. It is a VR painting application produced by Google as collaboration between artists and

scientists, enhancing creative practice opportunity for users and their 3D artwork created VR space with sharing creations online. More so, turning the 3D VR object into a holographic format for the wider public (Pioaru 2017).

An exploration on virtual clay modeling and tools was presented in the literature (Sener et al. 2002). The authors investigated attempts offered on using haptics for force-feedback that was used by Gribnau (1999). They also suggested using CAD tools to generate 3D objects using PHANToM haptic device's human-computer interface technology for users to touch and manipulate virtual objects, considering free-form for a better development process. Sener's approach gave a solid ground to develop the concept of VR clay modeling and prototyping. This approach supported the idea of integrating the system and methods to establish a VP novel system by Dashti et al. (2020a). The integrated 3D graphics toolkit software system showed new opportunities and challenges to enhance computer graphics and traditional pottery-making fields.

Why Deformable Shape Modeling?

Deformable shape modeling is a reliable, functional method for computer graphics, modeling a realistic volumetric geometric texture. This approach provides more accurate, pragmatic variable data of deformational behavior. The technique produces volumetric deformation of, e.g., height, depth, twist, and bend for medical scientists, artists, and engineers to enhance their performance and outputs.

Challenges in 3D Graphics Shape Modeling

Computer graphics modeling is considered expensive, as well as labor and compute-intensive. 3D modeling tools mainly creates rigid object surface with texture deformation to offer limited visual appearance of a detailed representation.

Deformable Shapes in Surgery Simulation

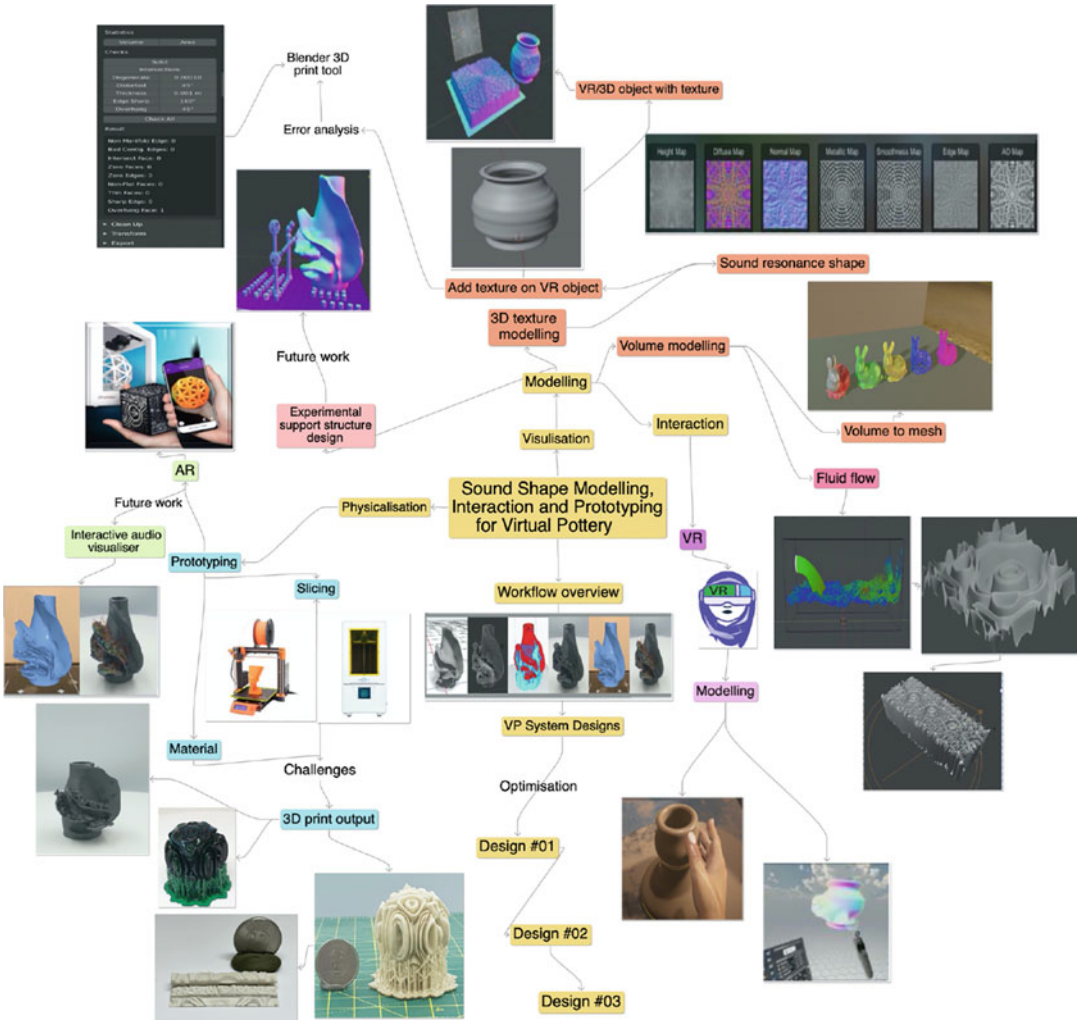
The approach for surgery simulation is an advanced deformation system that uses a parametric model by Liu et al. for Surgery Simulation. Haptics on 3D deformable models is a challenge because of the inevitable and expensive 3D deformation computation. In their paper, the authors proposed a technique that extends the conventional rigid approach using geometry images. Their approach flattens the geometry and also helps to accomplish deformation effectively and efficiently. They demonstrated that their method is suitable for haptics computing to perform the deformation on the geometry map to avoid expensive 3D deformation computation. They presented the construction of the deformable geometry map representation and its application utilizing practical methods for interactive surgery simulation and interactive textile simulation (Liu et al. 2007). This parametric approach has potential for the proposed Virtual Pottery application.

Deformable 3D Shapes in Facial Animation

Zhang et al. introduced a method of exploring the real natural deformation of a human face, using animated representation. The system relies on a physically based 3D facial model-based with anatomical knowledge. The approach involves a dynamic, non-linear multi-layered skin model where the skin is built as a mass-spring-damper (MSD) facial model (Zhang et al. 2004). In Chen and Prakash's face simulation (Chen and Prakash 2006), the authors use an animation system for a personalized human head. The deformation from the template model to the target head is through adaptation. Both general Radial Basis Function (RBF) and Compactly Supported Radial Basis Function (CSRBF) are applied to ensure the fidelity of the global shape and face features. Animation factor is also adapted so that the deformed model still can be considered as an animated head. Situations with insufficient scanned data are also discussed in their paper. A related approach by Navarro-Newball et al. (2011) builds up a face using anatomy guided bottom up creature skinning. These approaches have the potential for multilayered shape modeling for virtual pottery.

Deformable 3D Shapes in Artistic Simulation

Dashti et al. presented a demonstration of a novel method using off-the-shelf tools to discover unique texture for VP interactive modeling, a novel approach for virtual pottery, 3D modeling



Imagineering Ceramic Pottery Using Computer Graphics, Fig. 1 Imagineering the virtual pottery workflow

with augmented reality interaction technique for materializing deformable shapes sound-resonance on 3D objects. The technical framework provided a new method using simple processes to perform complex object transformations for virtual, 3D modeling and augmented reality interaction. Clay-based VR modeling uses the concept of deformable shape modeling to extend physical ceramics. It captures the visual and physical representation deformation of actual ceramic making (Dashti et al. 2020b). Clay as material presents some challenges of preserving real-world constraints, such as gravity and evaporation, capturing the artist's creative physicalized imagination. Figure 1 shows the different elements of imagineering for the virtual pottery system and captures the relation between the various aspects. Figure 2 shows an example of an object that has undergone the imagineering process and realized in a physical form.

This approach augments realistic shape and surface transformations, using 3D surface mesh sculpting with voxel-based geometry. The volumetric 3D Sound-Structure Texture Modeling process first includes materializing sound resonance from fractal images, using Chladni plate software with bump and displacement mapping. Next, volumetric deformable shape maps are

Imagineering Ceramic Pottery Using Computer Graphics, Fig. 2 Physicalized output from the virtual pottery imagineering system

blended on the surface of the VR object to combine intricate sound resonance patterns. The procedure is then extended to transform the output of complex 3D shape models from the above steps for rapid prototyping using appropriate pre-print tools by remeshing and physics manipulations.

Conclusion

The time has come for Imagineering Ceramics Pottery Using Computer Graphics. This work has highlighted the imagineering map with several elements seamlessly integrated. Challenges still remain where every element can be expanded with more realistic features. One specific area of immediate focus in this work is Imagineeramics, to look at the full functionality of imagineering with ceramic material properties. It is all in the imagination of the artist and computer scientist to push the boundary forward.

Cross-References

- 3D Avatars in Virtual Reality Experience
- Artistic Data Visualization in the Making
- The New Age of Procedural Texturing
- UV Map Generation on Triangular Mesh

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Immersion

▶ Game Design and Emotions: Analysis Models
▶ Mixed Reality and Immersive Data Visualization
▶ Videogame Engagement: Psychological Frameworks
▶ Virtual Reality System Fidelity

Immersive

▶ Virtual Reality as New Media

Immersive Auralization Using Headphones

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Synonyms

Earphones; Headphone; Headphone impulse response; Headphone transfer function; Headphones; Headset

Definitions

Headphones are electro-acoustic transducers able to convert two electric output channels into two dichotic acoustic signals at user's ears, preferably binaural signals. The less distortion and flat response headphones hold the more control of sound parameters and auralization accuracy game developers and designers can obtain. Headphone-induced spectral coloration and distortion is a key factor in music listening but even more critical in future immersive virtual and augmented reality scenarios where users directly compare their real life sensory experience with realistic multimodal synthetic stimuli and interactions.

Introduction

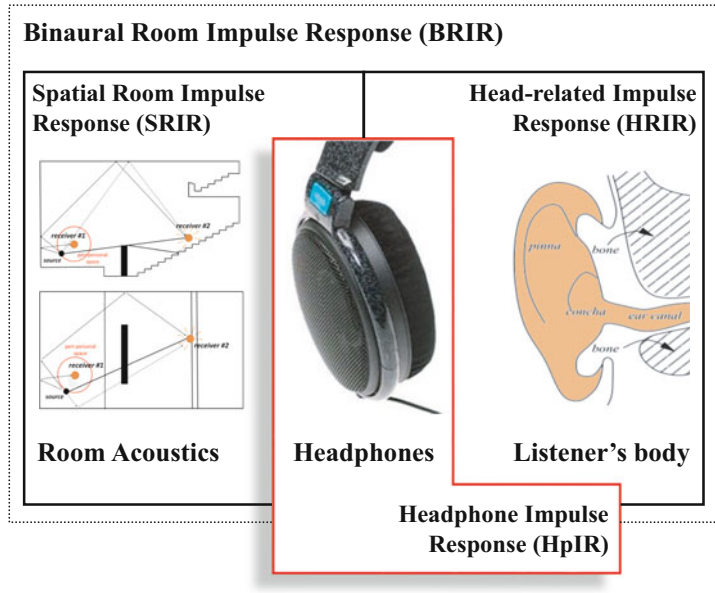
In order to deliver natural auditory experiences in virtual/augmented reality with headphones, sound pressure level (SPL) of the synthesized sound field has to be delivered at user eardrums coherently with their natural listening experience (see Fig. 1 for a general schematic view). In particular, auralization algorithms should rely on a well calibrated audio equipment and individually equalized headphones (see "▶ Sound Spatialization").

Sound transmission from headphone to eardrum can be represented through an analogue circuit model (Møller 1992) with the ideal goal to obtain:

$$Z_{\text{headphone}} \approx Z_{\text{radiation}}, \quad (1)$$

where $Z_{\text{radiation}}$ denotes the equivalent acoustic impedance outside the ear canal in free-field listening conditions, and $Z_{\text{headphone}}$ the equivalent impedance outside the ear canal with headphones. This equation can be interpreted as follow: the opposition that headphone present to the acoustic flow, i.e., playback audio signals inside ear-canals, should be comparable to natural listening conditions without headphones. The validity of such model is restricted to wavelengths greater than the ear canal's width, i.e., approximately under 10 kHz, leading us to define the so-called Pressure Division Ratio (PDR) as the ratio between the pressure divisions of two situations:

- Open/blocked ear in a natural listening conditions with an external sound source in anechoic space
- Open/blocked ear when the sound source is the headphone driver



Immersive Auralization Using Headphones, Fig. 1 High-level acoustic components for VR auralization with focus on headphone interaction

One can formally define the PDR as follow:

$$\frac{P_{\text{open}}}{P_{\text{blocked}}} = \frac{P^{Hp}_{\text{open}}}{P^{Hp}_{\text{blocked}}}, \tag{2}$$

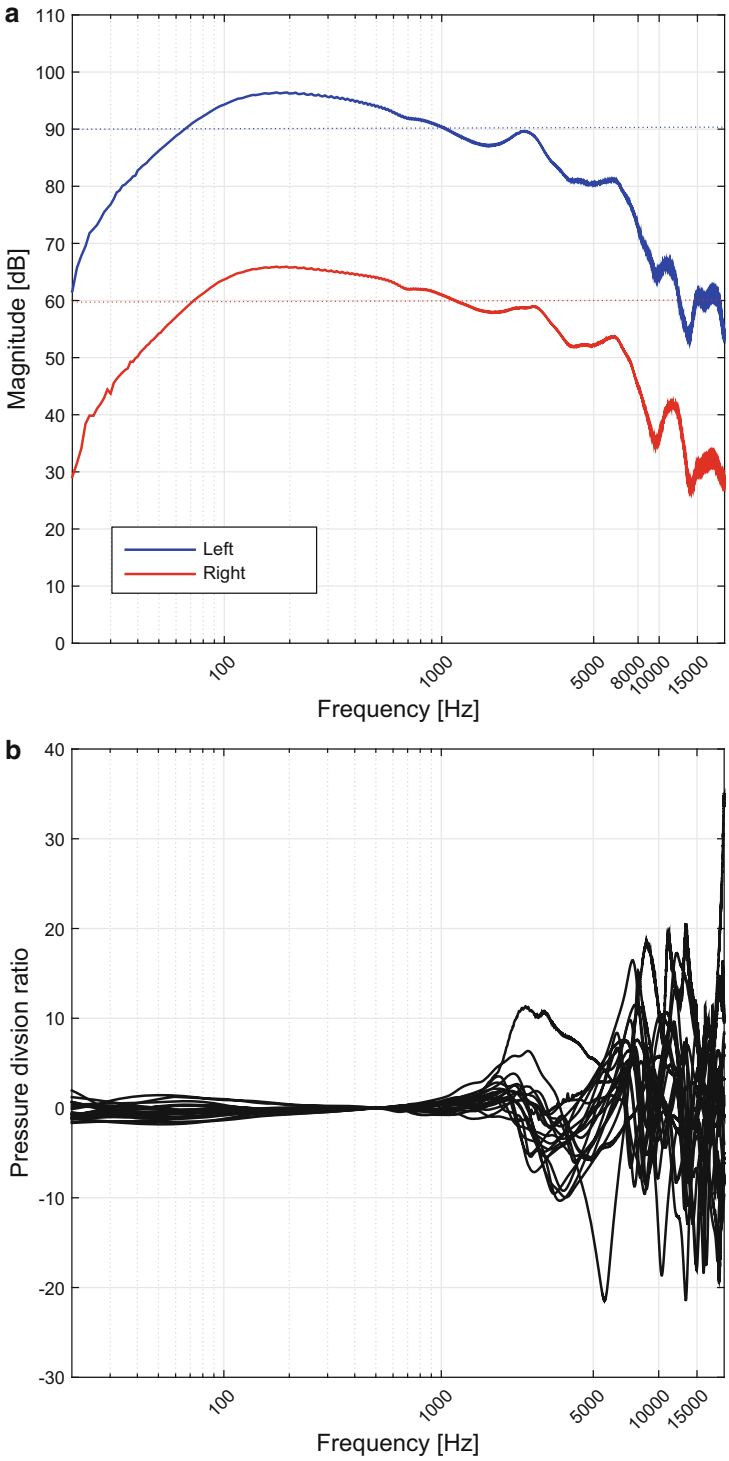
where P_{open} and P_{blocked} stand for the free field sound pressure at the entrance of the open- and blocked-ear canal, respectively, while P^{Hp}_{open} and P^{Hp}_{blocked} indicate the same sound pressure observation points when the sound source is a headphone. Figure 2b depicts an example of PDR computation for 18 users. Headphones with PDR ≈ 1 satisfy the free-air equivalent coupling (FEC) criterion (Møller 1992) where the acoustic load to the ear canal is equal to the radiation impedance of ears without headphones. Headphones act as an acoustic cavity that introduces a constant level variation at low frequencies, i.e., ≈ 4 kHz, with few inter-subject variability. On the other hand, headphone position and user's external ear anthropometry introduce frequency notches in the higher spectrum. Headphone- and user-specific acoustic interferences are difficult to predict and compensate in order to have a robust flat headphone response for auralization.

Sources of Variance in Binaural Signals

Audible artifacts and unnatural spectral coloration are likely to occur in the reproduction of binaural signals with headphones. In Brinkmann et al. (2017), a summary of main sources of error was reported taking into consideration authenticity of audio rendering, i.e., the perceptual identity with a real acoustic event (Blauert 1983). In Table 1, only key factors and average acoustic errors related to headphones are reported.

It has to be noted that the major sources of error are headphone repositioning and presence. The first source is closely related to headphone form factors and robustness to movements, while the second mainly affects comparisons between natural listening experience and binaural audio rendering with headphones in tests on authenticity where participants are usually asked to evaluate both conditions without removing and putting headphones on.

The mix of standing waves that start to grow inside headphone cups, with outer ear's resonances, results in an individual characterization of headphone acoustics. Headphone form factor (i.e., circum-aural, supra-aural, extra-aural, earbuds, and inserted) heavily influences all these sources of variation. Headphone acoustic



Immersive Auralization Using Headphones, Fig. 2 Example of headphone transfer function for SENNHEISER HDA200 supra-aural headphones over a 20 human heads; data are taken from BT-DEI HPIR database, part of the PHOnA archive (Boren et al. 2014). (**a**) Average magnitudes considering all 18 individual HpTF sets with reference calibration 90 db_{SPL} at 1 Khz (dashed blue line and $-$ 30 db_{SPL} shifted dashed red line are left and right channels, respectively), (**b**) variability on pressure division ratio across human heads

contribution can be described by headphone impulse response (HpIR) measurements or their frequency domain counterpart, i.e., headphone transfer functions (HpTFs). HpIRs are typically measured on an (i) artificial ear (e.g., B&K 4153), (ii) a dummy head (e.g., KEMAR mannequin

Immersive Auralization Using Headphones, Table 1 Sources of errors and variance due to headphones for binaural reproduction

	Typical error (dB)	Maximum error (dB)
Headphone repositioning	5	20
Acoustic headphone load	4	10
Headphone presence	10	25
Headphone compensation	1	10

(Gardner and Martin 1995)), or (iii) human listeners. Since, the first two measurement methods do not consider inter-subject and intra-subject variability, individual recordings should be preferable in order to take into account multiple positionings of headphones and to fine tune headphone compensation algorithms for a specific user. However, this latter approach is not practicable for a wide population of users; accordingly, headphone equalization algorithms usually rely on average HpIR responses for compensation which is based on available measurements for a specific headphones on a group of users thus accounting only for headphone contribution (see Fig. 2a for an example); moreover, regularization methods act on high-frequency gain in order to further level out user-dependent variations (Schärer and Lindau 2009).

It has to be noted that virtual and augmented reality applications require different headphone levels of isolation or transparency making the choice of a proper headphone design and equalization algorithm critical. Since noise-canceling headphones can be considered an extreme example of acoustic isolation from the real world, hear-trough devices require all the external acoustic information to be collected and processed together with virtual sound sources (Valimaki et al. 2015).

A high level of authenticity for a virtual auditory display can be achieved using extra-aural headphones where the acoustic coupling between listener and headphones is minimized (Romigh et al. 2015), thus resulting in less influence of the playback device on a recorded/synthesized sound-field; however, external sound sources easily interfere with auralization, and head movements could cause large variations in placement of suspended headphones, thus leading their use for only research purposes. On the other hand, the scientific literature suggests that circum-aural Sennheiser HD600 is usually adopted as a de facto standard for a broad variety of psychoacoustic studies on binaural reproduction. This headphone model fulfills FEC criterion; however, it do not allow isolation from external sound sources. In order to overcome the isolation issue, in-ear headphones seem to introduce smaller intra-subject variability (less inclusion of pinna contribution) once the quality of the sealing is high (Olive et al. 2017), at the cost of a nontrivial compensation for ear occlusion.

Conclusion

Auralization relies on the amount of individualization in the headphone correction of both measurement techniques (e.g., average, generic, and individual HpIRs) and equalization methods with emphasis on high-frequency control in the inverse filtering problem (Boren et al. 2015).

In-situ individual calibration for a transparent headphone response is a challenging research issue with no straightforward procedures, especially for inserted earphones that do not satisfy FEC criterion. Novel technological advances are contributing to the integration of headphones in even more smart headset, introducing a binaural earphone-plus-microphones system which will be able to extract the ear-canal transfer function (ECTF) in real-time and to perform an adaptive inverse filtering able to estimate sound pressure of an occluded ear canal (Denk et al. 2017).

Cross-References

- ▶ Overview of Virtual Ambisonic Systems
- ▶ Sonic Interactions in Virtual Environments
- ▶ Sound Spatialization

- ▶ Spatial Perception in Virtual Environments
- ▶ Training Spatial Skills with Virtual Reality and Augmented Reality
- ▶ User Acoustics with Head-Related Transfer Functions

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Immersive Design

- ▶ Foundations of Interaction in the Virtual Reality Medium

Immersive Environments

- ▶ Virtual Reality Systems, Tools, and Frameworks

Immersive Storytelling

- ▶ Storytelling in Virtual Reality

Immersive Systems

- ▶ Foundations of Interaction in the Virtual Reality Medium

Immersive Tech

- ▶ Immersive Technologies for Medical Education

Immersive Technologies

- ▶ 3D Avatars in Virtual Reality Experience
- ▶ Everyday Virtual Reality
- ▶ Immersive Visualizations Using Augmented Reality and Virtual Reality

Immersive Technologies for Accessible User Experiences

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Synonyms

Extended reality; Usability; User experience

Definition

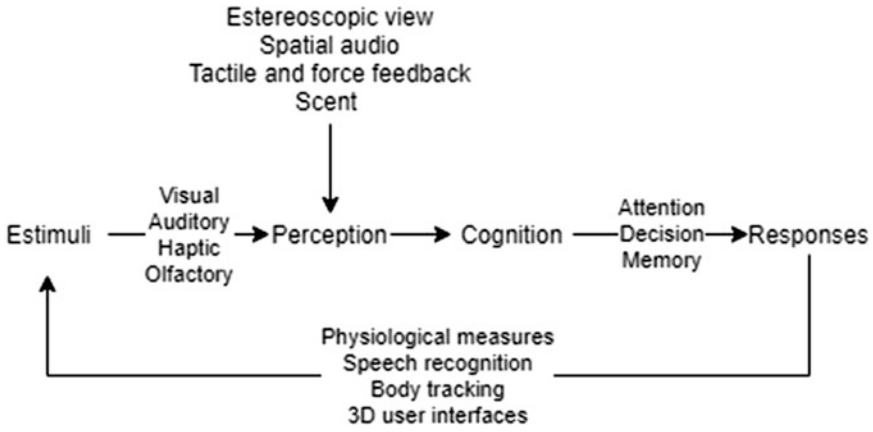
Immersive technologies encompass hardware and software that provide sensory feedback in the form of visual, auditory, haptic, or olfactory cues employing diverse human interface devices. Coupled with human-centered design considering varying human factors associated with perception, cognition, and physical ergonomics, these technologies aim to provide accessible user experiences. Although accessibility is typically associated with removing barriers for those experiencing disabilities, usability should be used instead because its purpose is the ease of use regardless of the end-user.

Introduction

Immersive technologies enable cross-sensory experiences that blur the frontier between virtual and real worlds (Suh and Prophet 2018). The cross-sensory stimuli are also referred to as multimodal or cross-modal because of the use, combination, integration, or translation of sensory cues into diverse installations (i.e., artistic, educational, training, or health care, among others), which affect the user experience (Kapralos et al. 2017). Currently, Virtual and Augmented Reality, VR and AR, respectively, are becoming ubiquitous with off-the-shelf products including mobile devices, video game-handheld devices, and headsets, which are becoming readily available. Furthermore, there are several high-end and industry-grade immersive technologies, for example, Mixed Reality (MR) devices such as the Microsoft HoloLens 2 offer holographic projections blended into the real environment, which are currently used in medical, defense, and automotive applications (Speicher et al. 2019). Although VR, AR, and MR can provide highly immersive and engaging user interactions, these technologies typically offer isolated experiences, and recent trends favor social symmetric and asymmetric experiences (i.e., those were users share the experience using the same technology or different devices, respectively) (Jeong et al. 2020). The interconnectivity of these immersive technologies is allowing cross-platform interactions, where VR users can interact with those using AR or MR thus producing eXtended Reality (XR) experiences (Skarbez et al. 2021).

Immersive technologies interconnect human factors within interaction loops. The users will process the perceptual information to make decisions and interact with the virtual environment while receiving sensory feedback as shown in Fig. 1. Depending on the experience (e.g., leisure, entertainment, training, or education), actions or information may be stored in either the short- or long-term memory. Within the interaction cycle, attention influences how the users gather spatiotemporal information. Attention is required for the orientation of sensory events and detection of signals for processing, which has been predominantly achieved through visual stimuli (LaViola et al. 2017).

The perceived visual, auditory, and haptic stimuli allow users to act and execute tasks through a combination, substitution, or translation of sensory cues. This is required in order to compensate for the limitations of immersive technologies with respect to providing realistic perceptual information. For example, the lack of visual feedback for localization tasks can be replaced by auditory cues (Massiceti et al. 2019), and the combination of haptic and auditory cues can further enrich localization skills for those with vision impairment (Reynal et al. 2019). The cross-sensory cues enable mental processes associated with thinking, remembering, and decision-making, also referred to as



Immersive Technologies for Accessible User Experiences, Fig. 1 Interaction loop

cognition. The cognition process can be further understood by analyzing in-experience metrics such as time to completion, task completion, and information from physiological sensors including eye tracking, heart rate, brain activity, muscle activity, and skin responses (Fralish et al. 2018).

A meta-analysis on AR in education highlighted the importance of the acquisition of social, living, learning, and physical skills for users with cognitive disabilities (Baragash et al. 2020). A recent study into VR adoption in K-12 for students with disabilities revealed the prevalent use of non-immersive screen-based interventions that do not take advantage of the immersive and interactive capabilities of immersive VR (Carreon et al. 2020). The current availability of consumer-level XR technologies has sparked interest in developing accessible user experiences through customized interactions employing speech recognition (Bryant et al. 2020), body tracking (Shao et al. 2020), gaze tracking (Saha et al. 2019), and custom-made human interface devices (Mirzaei et al. 2020).

Visual Perception Technologies

Predominantly, the visual domain is the most used in immersive technologies and has seen the most advances. Immersive visual cues rely on the capacity to perceive depth, which is achieved by VR headsets employing stereoscopic views seen through biconvex lenses. Figure 2a presents the Oculus Quest 2, a VR headset featuring inside-out tracking for seated, standing, and room-scale VR. The ability to customize the interactive volume allows using VR as a portable solution for travel training for people with intellectual disabilities (Checa et al. 2019). Figure 2b presents the Aryzon AR headset, which uses an array of mirrors that create the effect of holography, and unlike traditional AR, the Aryzon headset is hands-free. AR is the immersive technology which is the most widely available to users as it can be used with most medium-range mobile devices, including phones and tablets. AR has been used to facilitate wheelchair indoor navigation by informing users about obstacles and hazards in planning safe routes (De Oliveira et al. 2017). Additionally, AR has been used to help those with dyslexic impairment to decrease the overall time required for reading by enabling text customization adjustments, including background contrast among others (Gupta et al. 2019). Finally, Fig. 2c presents the Microsoft HoloLens, a headset that overlays virtual content in the real world by mapping the environment, thus creating holographic visual feedback. User interactions occur through remote control, hand tracking, voice recognition, and eye tracking.

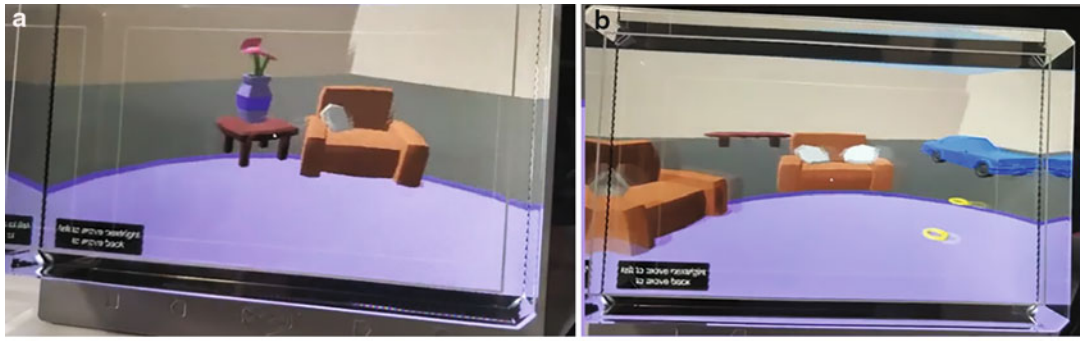
Within the field of visual immersion, holographic displays are gaining momentum due to their capacity of providing visualizations with depth to multiple users without requiring a

Immersive Technologies for Accessible User Experiences, Fig. 2 Head-mounted displays for immersive technologies

(a) Oculus Quest VR HMD

(b) Aryzon AR headset

(c) Microsoft HoloLens



Holographic view from the right

Holographic view from the center

Immersive Technologies for Accessible User Experiences, Fig. 3 Looking Glass holographic display of a living room for reminiscence therapy purposes (Tabafunda et al. 2020)

headset. Nonimmersive displays enable users who cannot use a headset to experience the virtual content. Figure 3 presents two views from a living room scene rendered on the Looking Glass holographic display for reminiscence therapy, an intervention that helps individuals with dementia to recollect memories from their past (Tabafunda et al. 2020).

The use of holographic displays and tethered VR and MR HMDs requires a VR-ready computer, which makes this solution accessible to few users. A consumer-level solution to this problem is using nonimmersive VR where users navigate the environments through a regular screen. The addition of motion parallax effects concerning the user's head position and orientation can be used with regular screens to provide depth perception. Figure 4 presents the nonimmersive VR motion parallax implemented with a web camera, the FaceTrackNoir library, and the Unity game engine. Figure 4 shows how the foreground tree occludes the cherry blossom when moving from left to right. Similar motion parallax effects can be achieved employing depth sensors such as the Azure Kinect for providing more realistic telepresence human interactions (Tölgyessy et al. 2021).

Visual Tracking Technologies

Measuring and driving user interactions employing eye tracking for understanding human cognition in immersive technologies is a relatively novel field. Eye tracking allows capturing information associated with gaze, regions of interest, and attention span (Clay et al. 2019). Recently, advances in eye tracking have led to the use of foveated rendering for improving attention and rendering optimization by increasing the visual fidelity of the areas of interest where the gaze is attending (Matthews et al. 2020). Concerning accessibility, Masnadi et al. (2020)

developed an eye-tracking assistance tool that projects corrections designed to help people with visual impairments.

Currently, off-the-shelf VR devices offering eye-tracking capabilities include the HTC Vive Pro Eye and Pico Neo 2, both featuring Tobii eye-tracking technology. Pupil Labs also offers eye-tracking add-ons that can be attached to various immersive technology hardware including Microsoft HoloLens 1 and eyewear for AR. In contrast to the Microsoft HoloLens 1, the Microsoft HoloLens 2 integrates eye-tracking technology without requiring additional hardware. Figure 5 presents a view of the HTC Vive Pro Eye and Pico Neo 2.

Auditory Perception Technologies

Second to vision, auditory cues provide perception of direction and distance from the audio source. Spatial audio applies directional audio filters by adjusting the frequencies and delays of what is heard by each ear (Tashev and Gamper 2017). The output causes the sensation of hearing sound from different directions when navigating the virtual environment, which can be used as travel aids for visually impaired users (Spagnol et al. 2018). Spatial audio can also be used to increase empathy and awareness concerning activities performed without visual cues (Guarese et al. 2021). For example, Cowan et al. (2020) developed a framework for analyzing the effects of sound rendering in a virtual environment, where participants navigated a virtual world through the localization of audio sources, concluding that improvements in spatial audio rendering do increase task performance.

Except for mobile AR, current VR, and MR, HMDs feature spatial audio through embedded speakers either on the headband (e.g., Oculus Quest, Oculus Rift S, and Microsoft HoloLens), or ear speakers hovering on top of the ear (e.g., Valve Index). As a result of advances in binaural rendering and sound-based physics, spatial audio provides more accurate auditory representations than stereo or surround sound, which is limited to environmental recordings on multiple channels. Because of these properties, spatial audio can be used as a substitute for visual cues to help users

Immersive Technologies for Accessible User Experiences, Fig. 4 Nonimmersive VR motion parallax moving from left to right

(a) Left (b) Center (c) Right

(a) HTC Vive Pro eye VR HMD (b) Pico Neo 2 VR HMD

Immersive Technologies for Accessible User Experiences, Fig. 5 Lens- and eye-tracking view for the HTC Vive Pro Eye and Pico Neo 2

with various degrees of sight loss to navigate virtual environments, such as a virtual conference venue (Robern et al. 2021). Research in this field has produced methods for mapping visual navigation to auditory cues employing echolocation and distance-dependent hum volume modulation (Massiceti et al. 2019).

Speech Recognition Technologies

Speech recognition plays an important role in immersive interactions as it allows to create more natural user-avatar interactions by facilitating speech-to-text, text-to-speech, and enabling automated dialogues driven by emotion recognition, physical interactions, and physiological measures (Cinieri et al. 2020). A review conducted by Nassif et al. (2019) identified the prominent use of machine learning in English settings determining efficiency through word-error-rate, concluding the need for employing recurrent neural networks to yield better results. For example, Teófilo et al. (2018) developed a system that employs language to assist deaf and hard of hearing users to improve speech understanding by supporting sentence prediction and spelling correction. Artificial Intelligence (AI) has been renewed in speech recognition thanks to the advances in smart assistants in mobile phones and smart assistants as it allows for creating natural user interactions to help users with disabilities interact with the virtual environment, whether for avatar interactions to help users with autism to better understand emotions through audiovisual cues (Yuan and Ip 2018) or facilitating communication through the interpretation of sign language (Cheok et al. 2019).

Somatosensory Perception Technologies

Kinesthetic and proprioceptive cues, pertaining to the somatosensory system, allow for the feeling of textures, object properties, objects in motion, and a perception of self. Within this system, haptic feedback or the sense of touch plays an important role in immersion and presence as it enhances perception to the point that it can be used to replace visual and auditory feedback. Sorgini et al. (2018) conducted a literature review on haptic technologies for auditory and visual sensory disabilities, where it highlights the importance of sensory substitution employing consumer-level technologies to facilitate interactions with nondisabled peers.

Vibrotactile feedback is the most commonly used technology due to the miniaturization of actuators, its low-cost, and the seamless integration inside VR controllers, gamepads, clothing, and custom-made 3D-printed user interfaces. For example, virtual environments can be coupled with a walking cane to provide auditory and haptic cues to enable training and increase awareness when navigating unknown locations (Zhao et al. 2018). Kim et al. (2021) developed a human-display interface with vibrotactile feedback for assistive applications such as devices relying on touch screens found in vehicles, wheelchairs, and public locations such as airports, hotels, and shopping malls. Vibrotactile feedback is limited to cues associated with vibrations, taps, pressure, and pinching feedback through skin deformation. This limitation of vibrotactile feedback impedes the capture of Kinesthetic cues that allow determining the physical relationship with objects. Force feedback haptic devices, on the other hand, require mechanisms that transfer mechanical movement to the user through actuators that respond to the user's inputs.

Wearable haptic devices for visually impaired users provide AR installations featuring gesture tracking and haptic gloves that enable computer interactions including writing emails, storing and retrieving files, making video calls, and accessing email, among others (Kalra et al. 2021). Theil et al. (2020) developed a tactile board for users who are both deaf and blind as a tool for translating text and speech into vibrotactile cues displayed through a wearable haptic user interface. Wang et al. (2018a) developed an intelligent wearable controller for people with motor disabilities employing machine learning and noninvasive sensors to drive computer interactions based on eye muscle movement and facial expressions.

Olfactory and Taste Perception Technologies

Finally, olfaction and taste respond to chemical cues that are underrepresented in immersive technologies as these mainly provide feedback that is difficult to register. While significant technology development is lacking in this area, olfactory feedback in VR has been investigated as it can add immersion and presence to the user experience by providing alerts, reinforce learning, and evoke memories and emotion. Casillas-Figueroa et al. (2020) conducted a study to assess the effectiveness of olfactory feedback in reminiscence therapy to provide additional feedback to the users.

Ergonomics

Ergonomics focuses on ensuring that the interactions are usable and effective with respect to the user's anatomy and physiology. Higher physical levels of immersion require taking advantage of human interface devices that capture the user's body and their interactions within the virtual environment. Currently, hand tracking is readily available in consumer-level VR through image processing (e.g., Oculus Quest and Microsoft HoloLens) as is finger tracking through proximity sensors (e.g., Valve Index controllers). Shao et al. (2020) developed a system for teaching American sign language in MR with noticeable improvements when compared to computer desktop learning. However, image processing with hand tracking lacks accuracy in comparison to data gloves that allow capturing dexterity more accurately (Ahmed et al. 2018). Furthermore, some gloves integrate diverse actuators to provide thermal, haptic, and force feedback (Wang et al. 2018b).

Locomotion is another field of interest as it enables users with limited mobility to experience virtual navigation. Virtual walking is typically achieved by means of head tracking, arm swinging detection, and custom-made foot-user interfaces in conjunction with 3D-user interactions such as teleportation (Cherni et al. 2020). However, it can also be accomplished by other input mechanisms including eye tracking, muscle activity, brain activity, speech recognition, or body gestures.

Although body capture is used to facilitate the interactions, users who experience limited mobility may require additional input devices to execute the virtual tasks. For example, brain-computer interfaces allow capturing cerebral activity that can be used to interact with virtual elements. Coogan and He (2018) proposed a modular system that allows users to customize the interactions based on their brain activity to empower users with autonomy. Bobrova et al. (2020) captured imaginary lower limb movements through a brain-computer interface as means to enable VR locomotion. Further customization employing physiological sensors is becoming readily available in VR and MR headsets, as well as mobile devices for AR.

Conclusion

Immersive technologies have shown their disruptive potential in changing how we engage with education, entertainment, fitness, and training. While the benefits have been documented toward the average user, the landscape is rapidly changing as researchers, developers, and enthusiasts have started developing inclusive experiences. The affordability of XR devices has increased the number of users who install base and sparked interest in sectors that were unable to use them due to costs or infrastructure requirements.

The adoption of XR has allowed to identify several areas of research associated with usability, user experience, body tracking, locomotion, motion sickness, user interactions, cognitive load, security, and presence, among others. While the hardware may come as one-size-fits-all, researchers are creating innovative solutions leading to novel devices, techniques, retrofitting, reverse engineering, and customization of immersive technologies for accessible user experiences.

Cross-References

- ▶ Augmented Reality
- ▶ Computer Vision
- ▶ Interaction

- ▶ Immersive Visualizations Using Augmented Reality and Virtual Reality
- ▶ Virtual Reality

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Immersive Technologies for Medical Education

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Synonyms

Educational simulation; Game-based learning (GBL); Immersive tech; Sim

Definition

Computer simulation	A recreation of real-world phenomena employing mathematical models that can be visualized through a computer-generated scene.
Immersion	Sensation of being in a computer-generated world created by surrounding hardware providing sensory stimuli. Can be a purely mental state or can be accomplished through physical means.
Presence	The feeling of being immersed in a computer-generated world.
Immersive technology	Devices that provide sensory stimuli to provide a sense of realism and immersion to the interactions with the computer-generated world.
Virtual reality	An interactive computer simulation which senses the user's state and operation and replaces or augments sensory feedback information to one or more senses in a way that the user obtains a sense of being immersed in the simulation (virtual environment).
Augmented reality	The addition of computer-generated objects to the real physical space to augment the elements comprising it.
Mixed reality	Integration of computer-generated graphics and real objects seamlessly.
Serious game	A video game whose primary purpose is education, training, advertising, simulation, or education as opposed to entertainment.

Introduction

Traditionally, medical education has followed the time-honored concept of "see one, do one, teach one," where theoretical education is followed by supervised clinical practice (Riener and Harders 2012). However, this approach is no longer viable and becoming less acceptable given the increasing focus on patient safety, care, and awareness, along with budgetary constraints associated with teaching in a clinical environment, particularly when considering invasive procedures that require high-risk care (Vozenilek et al. 2004). This increased awareness and focus on patient safety has been encouraged by studies that have examined medical errors and have suggested that as many as 98,000 Americans and 23,000 Canadians may die each year due to medical errors. Although the precise numbers have been debated, without a doubt, medical errors affect patient outcomes and health-care costs (Brindley et al. 2007). A proposed solution is a shift from the traditional "see one, do one, teach one" apprenticeship model of education to one where the transition from theory to practice is augmented by carefully designed simulated encounters with patients, teams, and health systems. Termed simulation-based education (SBE), this approach enables a replication of most clinical situations with various degrees of fidelity or realism, multimodality, immersion, and presence (Brindley et al. 2007). SBE can offer a viable alternative or complementary mean to practice a range of skills, attitudes, and behaviors ranging from cognitive, to communication, to crisis resource management, and to psychomotor to be developed by junior trainees or maintained by more experienced doctors (Brindley et al. 2007).

Per Halamek et al. (2000), simulation involves immersing the trainee in a realistic situation (scenario) created within a physical or virtual space (simulator) that replicates the real environment. In the context of medical education, simulation can be defined as an education technique that allows interactive and immersive activity by recreating all or part of a clinical experience without exposing patients to the associated risks (Perkins 2007). It has two components: the scenario and the simulator. The scenario is a description of a simulation that includes the goals, objectives, feedback or debriefing points, narrative description of the clinical simulation, staff requirements, simulation room setup, simulators,

props, simulator operation, and instructions for SPs (Alinier 2011). The simulator, on the contrary, is a setting, device, computer program, or system that performs simulation (Hancock et al. 2008), and can include manikins, cadavers, animals, devices, technologies, computer programs and virtual spaces, scenarios, standardized patients, and a host of other methods of imitating real-world systems (Curtis et al. 2012).

Simulation in medical education is a well-established pedagogical practice (Reznick and MacRae 2006). It provides a viable alternative to practice with actual patients, providing medical trainees the opportunity to train until they reach a specific competency level. Simulation ranges from decontextualized bench models and virtual reality (VR-)-based environments, to high fidelity recreations of actual operating rooms (Kneebone 2009). One of the prevailing arguments for using simulation in the learning process of trainees is the ability to engage the trainee in the active accumulation of knowledge by doing with deliberate practice, while it also allows for careful matching of the complexity of the learning encounter to the trainees' current level of advancement (Guadagnoli et al. 2012).

Although the economic evaluation in SBE is still in its infancy, recent reports suggest that the costs associated with this approach are high (Lin et al. 2017), yet if designed correctly they are cost-effective means of increasing the trainees' skills, knowledge, and attitudes (Isaranuwatchai et al. 2014). These costs are primarily related to the "simulator" part of the simulation equation. The simulation equipment and material costs are high due to low volume and costs of production. Finally, the depreciation, durability, and maintenance cost of the equipment also affect these costs. The purpose of this equipment is to allow the trainees to make errors and therefore the equipment wears out quickly. Another cost is that of personnel, which includes faculty members' time, confederate and actor training (Adler et al. 2016), administration staff and instructors, and a site champion to maintain interprofessional leadership, team management, evaluation of the program, and quality assurance of the training (Walsh and Jaye 2013). Finally, other costs include the maintenance of the simulation facility, often referred to as simulation laboratory. Collectively, although SBE has been shown to be an effective tool in providing new learning opportunities that lead to more skilled trainees and safer practice, it is expansive. Therefore, the field of SBE is in search of more cost-effective solutions which can augment the current educational practices.

Immersive Technologies

The technologies of video games, virtual worlds, and social networks have become collectively known as immersive technologies because of their ability to engage users of all ages, driving massive investment into technologies to attract, capture, and retain our attention (Wortly 2014). The increase in computational processing power and accompanying decrease in the size of electronic components has led to the decreasing cost and rising availability of consumer-level immersive technologies which have helped advance the adoption of virtual simulation in recent years. For example, hand and arm tracking technologies accomplished with controllers such as the Leap Motion hand sensor, the Razer Hydra, and the Thalmic Labs Myo interaction device are allowing for the development of novel interaction methods and techniques. Devices such as the Microsoft Kinect V2 motion sensor can track the position of the user's body and precisely track the movement of individual fingers in three-dimensional (3D) space. Haptic input devices such as the Novint Falcon or the 3D Touch Stylus provide a sense of touch and feedback to motion controls. Collectively, these devices provide more natural and immersive interactions, which in many applications help overcome the limitations associated with traditional keyboard and mouse-based human-computer interactions where tasks are performed very differently to a real-life situation. The current trend on natural user interactions is providing the designers and developers of virtual simulations with tremendous freedom and opportunities to develop highly immersive applications. The field of immersive/interactive multimedia applications (including virtual

environments (VEs) such as video games, virtual simulations, virtual reality, and serious games, that is, video games whose primary purpose is education, training, advertising, simulation, or education as opposed to entertainment), has seen significant advancement over the last couple of decades. The field of virtual reality alone is estimated to grow from $1.37 billion (USD) in 2015 to $33.90 billion (USD) by 2022 (Markets and Markets 2016), while a recent estimate by Goldman Sachs suggests the fields of virtual and augmented reality are expected to grow into a $95 billion market by 2025 (Hall and Takabashi 2017).

Current VR installments are seeing implementations in different areas given the possibilities to have users interact in safe, controlled, and monitored environments. Mihelj et al. (2014) define VR as "an interactive computer simulation, which senses the user's state and operation and replaces or augments sensory feedback information to one or more senses in a way that the user obtains a sense of being immersed in the simulation (virtual environment)." Virtual reality has also been defined as "the use of computer modeling and simulation that enables a person to interact with an artificial three-dimensional (3-D) visual or other sensory environment" (Riener and Harders 2012). At a minimum functionality, VR systems typically utilize a head mounted display (HMD), as the primary method for a user to view and interact with a virtual world. A HMD is a display device worn on a user's head which uses optical lenses and one or two small displays to show computer-generated imagery. These headsets typically use various sensors embedded in the device (such as accelerometers or gyroscopes) to translate real-world movement and rotation into corresponding changes of the view of the virtual world. A capability currently supported by modern mobile devices, whose sensors and mobile HMD provide consumer-level VR. Within the taxonomy of VR, mixed reality (MR), augmented reality (AR), and mixed reality providing various degrees of real and computer-generated images integration (Milgram and Colquhoun 1999). This scenario has caused interest in training and education due to visualization opportunities to enhance, complement, and augment the immersive scenario. Moreover, in medical applications AR has allowed visualizing medical data and the patient within the same physical space (Sielhorst et al. 2008). The skills acquired during virtual reality-based simulation training have been proven to transfer over to subsequent performance in operating rooms (e.g., see Seymour 2008).

During the last few years, there has been an explosive growth of interest in consumer-grade VR technologies, in part due to gaming and entertainment applications, with several players such as Facebook, Microsoft, and HTC investing in hardware and software to increase the VR install base. Since then, various competitors, including various technology company giants, have entered the marketplace. For example, Samsung has designed and developed the Gear VR, an inexpensive headset which uses the owner's mobile smartphone as the display and system processor. Sony developed the PlayStation VR which integrates seamlessly into the Sony PlayStation 4 console platform. At the Apple Worldwide Developers Conference (WWDC) 2017, Apple introduced the ARKit, an augmented reality platform that provides advanced augmented reality capabilities on iOS and will be supported by all phones that Apple releases. Facebook has acquired 11 AR/VR companies, stressing the company's view that VR and AR will "form the next frontier" (Hall and Takabashi 2017). The large investments and acquisitions by various large technology firms indicate that these technologies will become increasingly integrated with the platforms on which we consume content. The high-end consumer-grade VR option is currently held by Taiwan-based HTC's Vive device, a package including an HMD, two hand controllers, and two base stations used to track both the headset and controllers in a 3D volume of real-world space. In contrast to traditional VR ("seated") configuration where the user remains seated in a chair within the range of the motion tracking sensor, the HTC vive allows for room-scale VR whereby the user can freely move within the real world (e.g., walk around, face any direction, bend down to the floor), and have consistently tracked hand controllers within a wide space.

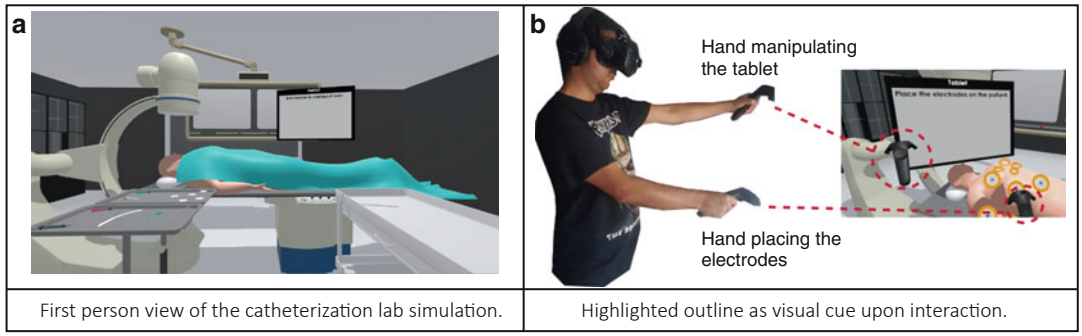
Traditionally, the video game industry has been the largest pushing influence of advancing certain technologies such as computer graphics and personal computer audio capabilities. This trend follows suit with the modern VR device companies specifically targeting video game players, with one such example being usable only with a video game console (the Sony PlayStation VR). Although video game players are historically early adopters of new, exciting, and expensive technologies, VR device companies should not neglect the possibilities in the space of serious games and virtual simulations for education and training. Modern consumer-grade VR devices are affordable, powerful, and will soon be adopted by the mass market. Although the strongest demand for immersive technologies currently comes from industries in the creative economy, and more specifically, gaming, live events, video entertainment, and retail, immersive technologies will find wider applications in industries as diverse as health care, education, the military, and real estate over time (Hall and Takabashi 2017). According to Huff and Saxberg (2009), immersive technologies – such as multi-touch displays; telepresence (an immersive meeting experience that offers high video and audio clarity); 3D environments; collaborative filtering (which can produce recommendations by comparing the similarity between your preferences and those of other people); natural language processing; intelligent software; and simulations – will transform teaching and learning by 2025.

Projections for the growth of the VR hardware industry are staggering, with some research firms suggesting the market will grow to $50 billion by 2021 (Sinclair 2016). This is driven largely in part by video game early adopters although VR and AR are rapidly entering into the medical education and health-care fields. Within the medical field, VR and AR are not so much technologies of the future but rather, of the present where researchers, doctors, and nurse educators are finding innovative ways to leverage immersive technologies and transform both health-care teaching and practice (Craig and Georgieva 2017). In fact, over time, it is anticipated that immersive technologies and VR/AR specifically will play a large role particularly under the following six medical-based applications (Gardner 2016): (i) education and training, (ii) surgical planning, (iii) telemonitoring, (iv) patient experience, (v) treatment and therapies, and (vi) augmented reality-enhanced surgery and patient care.

Examples of Immersive Technologies in Medical Education

Wilcocks et al. (2017) developed a virtual simulation of the angiogram procedure specifically to educate patients about the commonly performed angiogram procedure. Using an HTC Vive virtual reality headset, the patient is taken into a virtual catheterization (cath) lab and introduced to the angiogram procedure in a highly immersive, interactive, and engaging virtual environment. The goal of their simulation is to educate the patient about the procedure they will undergo and thus help reduce the fear often associated with the procedure, while increasing the patient's understanding and awareness, ultimately leading to greater patient outcomes (Fig. 1).

Shewaga et al. (2017) developed a room-scale epidural preparation serious game facilitated with an HTC-Vive headset that allows a user (trainee) to assume the role of a medical professional preparing to perform an epidural procedure (an injection into the epidural space around the spinal cord and spinal nerves). The serious game focuses on the cognitive aspects of the epidural procedure as opposed to the technical components, and more specifically, the steps of the procedure and what needs to be done at each step (e.g., reading a detailed patient anesthetic record, washing their hands, wearing proper operating room clothing, and gathering the various tools needed for the procedure and placing them onto a preparation tray). Using the epidural serious game, they conducted a quantitative and qualitative comparison between the usability, performance, and engagement of traditional desktop VR with a room-scale variation in order to develop a greater understanding of the differences between the two configurations and determine whether the additional requirements and resources


a
b
Hand manipulating the tablet
Hand placing the electrodes
First person view of the catheterization lab simulation.
Highlighted outline as visual cue upon interaction.

Immersive Technologies for Medical Education, Fig. 1 HTC Vive-based virtual angiogram simulation for patient education

associated with a room-scale VR configuration is warranted. Their quantitative results revealed limited differences between the two configurations, although the room-scale VR configuration did lead to higher immersion, and was generally preferred more among the participants. Greater work remains to determine whether one configuration is superior, but their results highlight the importance of considering the limitations of computer hardware when designing serious games and simulations, particularly when utilizing VR devices. Designers and developers of virtual simulations and serious games should consider the effects of the hardware being used and the requirements imposed upon it by the desired visual fidelity of the simulation. Higher fidelity implies greater computational requirements which may not be readily available to the average computer user (a discussion regarding fidelity, multimodal interactions, and perceptual-based rendering as they pertain to serious games is available by Kapralos et al. (2017)) (Fig. 2).

Conclusions

As computing power expands, new human performance monitoring technologies evolve, and the cost of simulation equipment falls, all medical training programs will need to devote substantial curricular time to SBE (Reznick and MacRae 2006). With respect to computer simulation (or in-silico simulation, depending on which way we go), VR is currently capable of providing a wide range of immersive experiences through numerous hardware that can provide various forms of sensory stimuli to achieve presence. This is of outmost importance in all VR installments as proper depiction of the tasks may affect the engagement and successful results. Moreover, in medical training the VR installments require the interactions to be tailored to match real-life scenarios to guarantee that the skills and competence can be transferred to live settings. That being said, it is important to consider the limitations of computer hardware when designing serious games and simulations, particularly when utilizing VR devices. There are numerous open research themes in VR, given the continuous hardware evolution and the high variability of users who may have motion sickness, 3D stereo blindness, and disabilities that would require adjustment to current hardware or the creation of new one, while addressing usability issues.

The future of SBE will, without a doubt, focus on introducing computer-based simulation with immersive technologies as part of blended modality approaches. That is, the different simulation modalities such as task trainers, manikin-based, standardized/simulated patients, computer-based, virtual reality, and hybrid play different roles in the educational journey of the trainee. Based on research to date, one can speculate that the choices and the use of various modalities in tandem with other ones will relate to the level of trainees, learning objectives, availability of resources, and

Immersive Technologies for Medical Education, Fig. 2 In-game first person view of the virtual operation room of the room-scale VR epidural serious game (user is shown in the bottom-right inset)

physical location (urban vs. rural training sites) to name a few.

Cross-References

- ▶ Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay
- ▶ Gamification and Serious Games
- ▶ Interactive Augmented Reality to Support Education
- ▶ Physical, Virtual, and Game World Persistence

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Immersive Virtual Reality Serious Games

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Synonyms

Learning; Rehabilitation; Serious games; Training; Virtual reality systems

Definitions

Virtual Reality	A model of reality with which users can interact using senses such as sight, sound, or touch.
Immersive Virtual Reality	A type of virtual reality in which the user's complete view is surrounded by the synthetic environment, as if they had stepped inside the virtual world. It is usually distinguished by the high level of immersion and interactivity offered.
CAVE	The abbreviation of Cave Automatic Virtual Environment, which is a virtual environment consisting of cube-shaped projection screens on the walls,

	floors, and ceilings surrounding the user.
Video Game	A game that is played by interacting with images in electronic form generated on a device such as computer monitor or TV screen.
Serious Game	A video game with a purpose beyond entertainment such as teaching users a new skill or training users to improve their existing skills on a subject.

Introduction

Virtual reality has become a prevalent tool in various areas because of the advancements seen in recent years. Video games constitute the major application area for virtual reality. Video games can be categorized in themselves according to their aims, such as entertainment games and serious games. In this entry, advantages and disadvantages of virtual reality and scientific studies in the area of immersive virtual reality serious games that has been published in the previous 10 years (between 2007 and 2017) are mentioned. The databases used were: Google Scholar, ACM Digital Library, IEEE Xplore, Springer Link, and Elsevier. The following keywords were searched in these databases: "Virtual Reality Serious Games," "Virtual Reality Learning," "Virtual Reality Education," "Virtual Reality Training," and "Virtual Reality Rehabilitation."

Advantages and Disadvantages of Virtual Reality

Several advantages and disadvantages of virtual reality have been identified in various previous studies (Dautenhahn 2000; Goldsmith and LeBlanc 2004; Parsons and Mitchell 2002; Putnam and Chong 2008; Rizzo and Kim 2005; Strickland 1997; Wang and Anagnostou 2014; Sharp et al. 2007; Hale and Stanney 2014). Major advantages of virtual reality can be summarized as follows: higher level of interaction fidelity; high level of immersion; active participation within virtual worlds; practicing in a safe environment; real time alteration of several attributes and parameters such as task complexity, environmental properties, and speed; reinforcement through infinite repetition using an automated system and software; easy variation and customization of content, tasks, and scenarios; highly structured automated training; high level of control on provided stimuli; increased focus of interest by isolation from surroundings; high degree of visualization which especially helps with abstract concepts; real-time prompts and feedback; no severe consequences of mistakes made during training; automated data collection and the ability of replaying recorded sessions for reflection afterwards; automated assessment and reporting; being appealing to technology savvy population.

On the other hand, some major disadvantages of virtual reality can be summarized as follows: motion sickness; disorientation; nausea; isolation and low degree of social interactions; requirement of wearing hardware which may be uncomfortable; price of special hardware, even though the technology is significantly affordable nowadays as compared to the previous decades; latency and frame rate problems; claustrophobia; risk of injury that may be caused by surrounding physical objects; hygienic concerns for multiple users sharing the same headset.

Immersive Virtual Reality Serious Games

This section includes recent immersive virtual reality serious game systems that focus on learning, training, or rehabilitation. There have been several studies that present virtual reality systems for learning. However, majority of these studies did not include immersive virtual reality systems but included desktop monitor displays or single screen projections. Many studies were published earlier than the 10 years limit this entry imposed.

Some recent works on immersive virtual reality for education are mentioned next. Du has worked on an experimental immersive virtual

reality system within a classroom learning context aiming to replace the traditional single projected screens in classrooms for more effective learning (Du 2014). Angulo and Vasquez de Velasco have developed an immersive virtual reality simulation system as an aiding tool for architectural spatial experience design (Antonieta 2014). Izatt et al. have constructed an immersive virtual reality system which functioned as an application for visualization and data interaction with the main goal of introducing new physics students and members of public to physical concepts such as Super-K, Hyper-K, the T2 K experiment, and water-Cherenkov detectors (Izatt et al. 2014).

Another major area for immersive virtual reality serious games is training. There have been several studies in the area of improving social skills of challenged populations. Cheng et al. have worked on using immersive virtual environments to improve the following social skill aspects of children with Autism Spectrum Disorder: nonverbal communication, social initiations, and social cognition (Cheng et al. 2015). Matsentidou has developed an immersive virtual reality system for improving social skills of children with Autism Spectrum Disorder via social stories presented in immersive virtual environments (Matsentidou and Poullis 2014). Lorenzo et al. have worked on an immersive virtual reality system that aimed to improve social and executive decision-making skills of children with Autism Spectrum Disorder with tasks that focus on school- and home-based social activities (Lorenzo et al. 2013). Ip et al. have worked on an immersive CAVE-like virtual reality system for training social adaptation of school-aged children with Autism Spectrum Disorder in inclusive education settings (Ip et al. 2016). Park et al. have developed an immersive virtual reality system for training individuals with schizophrenia on social skills such as conversation, assertiveness, and emotion expression via role playing in immersive virtual environments (Park et al. 2011).

Another emerging area for immersive virtual reality serious games is vocational training, especially catering for challenged populations. Bozgeyikli et al. have developed an immersive virtual reality system for vocational rehabilitation of individuals with cognitive and physical disabilities on several transferrable job skills (Bozgeyikli et al. 2017). Yu et al. have worked on an immersive virtual reality system that aimed to train individuals with hearing impairments on CNC machine operation skills (Yu et al. 2016). Sohn et al. have developed an immersive virtual reality projection based system for vocational rehabilitation of individuals with schizophrenia within the contexts of convenience store employee and supermarket clerk (Sohn et al. 2016). Webster has worked on an immersive virtual reality system that aimed to teach basic corrosion prevention and control knowledge skills to the US Army soldiers (Webster 2014).

Rehabilitation is another emerging area that includes several virtual reality studies. Some recent studies of immersive virtual reality rehabilitation systems are as follows: Maskey et al. have developed an immersive virtual reality system and utilized it along with cognitive behavior therapy to reduce some forms of phobia and fears such as crowded buses and pigeons in young people with Autism Spectrum Disorder (Maskey et al. 2014). Rooij et al. have worked on an immersive virtual reality system for improving balance and/or gait in rehabilitation of individuals after stroke (Rooij et al. 2017).

Limitations

This entry includes immersive virtual reality studies that were published in the last 10 years (2007–2017) and had a focus of learning, training, or rehabilitation applications. This entry does not include the following: entertainment games; commercial games; medical, military, or exercise serious games; and nonimmersive virtual reality studies that included desktop monitor, TV, or single projector displays.

Conclusion

The recent works mentioned are intended to give a snapshot of scientific studies in the area of immersive virtual reality in learning, training,

and rehabilitation. It was observed that the majority of the studies were catering for challenged populations. The diversity of application areas even within the three selected subtopics (learning, training, and rehabilitation) is encouraging for future studies in the area of immersive virtual reality serious games.

Cross-References

- ▶ Accessibility of Virtual Reality for Persons with Disabilities
- ▶ Gamification and Serious Games

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Immersive Visualizations Using Augmented Reality and Virtual Reality

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Synonyms

Augmented reality; Data visualization; Immersive technologies; Information visualization; Virtual reality

Definition

Immersive visualizations refer to a novel way of representing data and information through spatial computing technologies such as augmented and virtual reality. It aims to enhance the user perspective for enhanced insights from data and information to assist in the various processes including but not limited to decision making, enhanced learning, higher precision, and cost savings.

Introduction

Immersive technologies such as augmented reality and virtual reality have a transformational effect on how complex data and information is visualized. This trend has led to several applications across industries to adopt immersive visualizations. The reality-virtuality continuum has served as a reference framework for classifying different immersive technologies. The continuum was a continuous scale ranging between the completely virtual and completely real environment with visualization and immersion as the primary influencers (Milgram et al. 1995) (Fig. 1).

In this context, augmented reality, typically called as AR, is a technology that superimposes digital content on a user's view of the real physical world. It provides a composite view through a device such as a smartphone, a tablet, or a smartglass. The AR has core capabilities of information visualization, guiding the user and making the environment interactive through mediums such as gestures and voice (Porter and Heppelmann 2017). Latest developments in smartphone technologies such as sensor-based "simultaneous localization and mapping" (SLAM), 3D rendering, and camera capabilities have made augmented reality accessible to most consumers with better applications (Pangilinan et al. 2019).

Virtual reality, typically called as VR, is a computerized simulation of a new environment with visuals and interactions through a head-mounted device and controls. Vision, audio, and haptic feedback create experiences that feel like real. Virtual reality replaces physical reality with computer-generated content and adds the core capability of simulation in addition to AR (Porter and Heppelmann 2017). VR spectrum provides several usage patterns based on immersion and interactivity. Web browser-based non-immersive, noninteractive simple applications such as consumption of 360-degree photos and videos are at the lower end of the spectrum. At the same time, head-mounted device (HMD) based experiences with controllers and 6° of freedom provide complete immersion and real-time interactive experiences. The hardware requirements

Immersive Visualizations Using Augmented Reality and Virtual Reality, Fig. 1 Reality-virtuality continuum as a function of immersion (Milgram et al. 1995)

for these experiences vary based on their complexity and application (Pangilinan et al. 2019).

Mixed reality, typically known as MR, uses a combination of augmented and virtual reality to create engaging experiences. The extended reality, typically known as XR, is an umbrella term that covers augmented, virtual, and mixed reality. It also encompasses other supporting technologies such as AI (Artificial Intelligence), 5G, IoT (Internet of Things) to create engaging and interactive applications (Pangilinan et al. 2019).

AR and VR have wide-ranging applications across industries. Depending on the need for interactivity, immersion, and visualization, the applications make use of AR or VR appropriately. Enterprise sectors such as education, manufacturing, healthcare, military, real estate have seen early adoption of AR and VR for applications such as simulated walkthroughs, remote surgeries, combat training, employee training, and more (Carmigniani et al. 2011; Sicaru et al. 2017). Consumer segments such as retail, e-commerce, education, gaming, entertainment, and tourism also make use of AR and VR for applications such as virtual try-on for products (Bonetti et al. 2018, interactive books, interactive advertisements, immersive videos, virtual tours of famous places (Huang et al. 2016), and 3D interactive lessons Kosa and Uysal 2019).

Since the advent of Internet and mobile penetration, the amount of data and information processed in every enterprise and consumer application have grown exponentially. This situation poses significant challenges for users to make use of data and information for activities such as decision making, gaining insights, learning effectively, and collaborating. One of the critical elements that makes data accessible and usable for users is the visualization of it. The primary objective of data and information visualization is to facilitate learning and decision-making of users across the personal and organizational spectrum (Schintler and McNeely 2020).

As the complexity and volume of the information and data are increasing exponentially, the traditional methods of 2D and 3D visualizations on flat screens of computers or phones are not sufficient enough. Hence, emerging technologies such as AR and VR are being explored by researchers and businesses.

Need for Immersive Visualization

There are various reasons data visualization is increasingly becoming more critical in recent times. With growing complexity and volume of data, aggregation and creating insightful or delightful experiences is a significant challenge. The purpose of visualization varies based on applications, and some of the objectives are facilitating higher learning, speedier decision making, and keeping the user at the center of data and insights. This process must seamlessly work for general as well as professional users (Schintler and McNeely 2020).

Decision-making process analyses data to extract patterns and facilitate the discovery of knowledge or insights. Reducing the complexity of data to discover trends and anomalies lead to accelerated and more accurate decision making. Visual data mining techniques use human visual perception to gain insights from patterns. Immersive technologies assist significantly in this entire process (Moloney et al. 2018).

Scientific visualizations play an essential role in facilitating learning and information sharing among researchers, businesses, and government organizations. Applications such as stocks analysis or sports analytics are usually multidimensional and hence difficult to visualize on existing visualization technologies such as 2D or 3D. Entertainment and gaming applications require greater interactivity to enjoy the overall experience. Industrial applications, such as healthcare training or enterprise training, require a sense of physical presence to be more productive (Sicat et al. 2018). Due to these several complex situations, immersive visualizations become a tool of preference for personal and enterprise use.

Augmented and virtual reality have been extended from the original continuum to the multidimensional realm. Now it covers a sense of presence, level of interactivity, and the mechanism to achieve these through the embodiment of suitable devices (Flavián et al. 2019). In other words, the primary characteristics of immersive technologies such as fidelity with spatial, visual,

and aural senses of humans make it perfectly suitable for complex data and information visualization (Moloney et al. 2018).

Applications of AR and VR for Immersive Visualizations

This section presents a summary of applications from various industries which use immersive visualizations through AR and VR to facilitate decision making, learning, or experiences effectively.

Retail

Virtual Try-On of clothing or accessories through augmented reality is picking up among consumers as well as retailers. An in-store augmented mirror setup provides users with a digital catalogue to try-on for clothing and accessories. The proposed AR application gives an enhanced shopping experience compared to the physical model leading to higher customer satisfaction due to the speedier decision-making process for shopping. As a result, physical retail stores can provide greater choice to users similar to online methods and augment it with a sense of a physical presence (Bonetti et al. 2018).

A study was conducted that ingested data from neuro-scientific tools such as tracking eye movements, storing navigation, and selecting the brands in a virtual supermarket, performing data analysis, and thereby gaining insights about consumer choices, customer experience, and shopping behavior in a store. Qualitative analysis was also used to compare the choices of consumers and the subsequent outcomes and sales. The overall suggestions correlated high attention devoted to a brand and slow eye movements (between brands), to additional brand purchases within the category. The outcome of the results meant that that the additional brand choices drive the time buyers spent on the first choice. Hence, less time available for the first selection leads to additional purchases within the product category and increased sales (Bigne et al. 2015). This is a good use-case of how a VR environment was used to identify retail consumers' behaviors to improve product placements and, hence, increase sales.

Manufacturing/Production

The training and manufacturing process of assembling desktop computers is enhanced with AR to convert instructions manual into a step-by-step visual guide. The proposed AR app is a simplified process to follow for new employees without losing the task's context. The clarity of instructions leads to reduced errors and lesser training costs incurred by the organizations. Thus, productivity is higher, and product quality is also enhanced (Osborne and Mavers 2019).

By combining the manufacturing industry with VR technology, enterprises can remain competitive by utilizing quality inputs in new product developments. In manufacturing enterprises, by its visualization and immersive experience, VR helps in aggregating relevant information and enables faster decision-making during the product development processes. A thorough analysis shows the increasing use of VR technologies and further research being conducted to increase the practical use of VR technologies (Choi et al. 2015).

Education

A virtual tour of heritage locations provides immersive history and cultural experiences to students. In one of the examples, a 360-degree virtual simulation is created at the historical center of the city of Rethymno in Greece to teach ancient history and culture. A virtual reality application gives learners a higher attention span due to a virtual environment free of distractions. The additional sense of physical presence helps to facilitate greater understanding and engagement to the learners. The level of interactivity fostered through the VR application evokes higher interest in learners than just consuming content over the screen (Argyriou et al. 2020).

Real Estate

4D CAD models and immersive visualizations are used in structural steel framing operations to showcase the design and construction process to all stakeholders for approvals and updates.

Through effective visualizations, construction processes and operations are streamlined processes. The outcome means the decision-making process is effective due to lesser ambiguity reduced errors and greater participation and engagement of all stakeholders (Kamat et al. 2010).

Healthcare

Patient care and training in the poststroke phase are one of the healthcare use cases using immersive technologies. The rehabilitation of body-part functioning (such as hands) is enhanced through AR assisted devices for common tasks such as reaching out and grasping objects. The approach involving AR helps give haptic feedback, and the interactivity helps in accelerating the patients' rehabilitation process. The process is highly scalable due to the re-use of the virtual environment resulting in cost saving for patient care. As AR systems are easy to set up, the manual operations effort is reduced (Xun et al. 2005) (Fig. 2).

The surgical workplace is transforming with the help of emerging technologies like VR and AR. VR applications play an important role in healthcare by enhancing the medical use of data such as anatomy, intraoperative surgery, or postoperative rehabilitation. This process is accelerated by an increase in the availability and speed of VR hardware and a reduction in price (Khor et al. 2016) (Fig. 3).

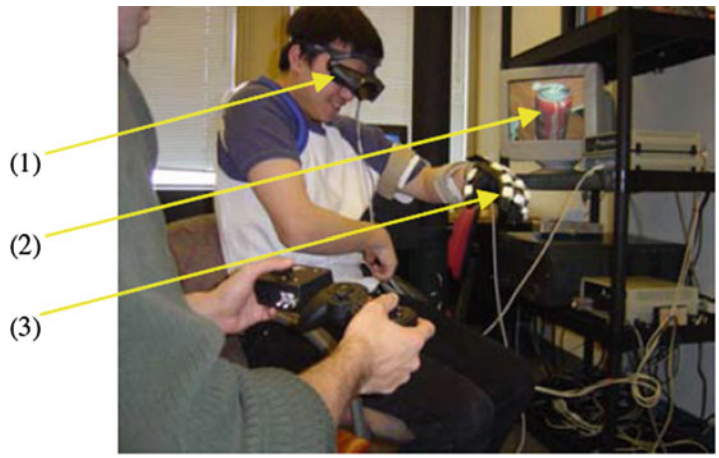
Tourism

Tourist destination marketing is using virtual reality to spread interesting information among customers. Creating interactive and informative virtual worlds to market tourist destinations is attracting customers. This method of using immersive visualizations provides higher consumer engagement and more credible marketing efforts resulting in less ambiguity for customers. Hence, marketers receive a higher satisfaction rate from their consumers as the immersive visualization of destination gives a more realistic look and feel of what to expect. The outcome is that the customers make their decisions faster (Huang et al. 2016; Huang and Liao 2015).

Augmented reality applications are enhancing the overall tourism experience by providing more context-specific information in a museum. The tourists could use their smartphone camera and augmented reality application to know interesting information such as history and facts about each article presented in a museum. This experience significantly adds value to the tourist's knowledge in a very engaging way without losing the context and language barriers in a foreign location (Yung and Catheryn 2019).

Wellness

Virtual reality and interactive, immersive games are being used to increase mindfulness. Its applications include therapy for pain management and mental wellbeing. The VR approach offers



Immersive Visualizations Using Augmented Reality and Virtual Reality,
Fig. 2 Rehabilitation process of the stroke patients using AR apps. (Xun et al. 2005)

Immersive Visualizations Using Augmented Reality and Virtual Reality, Fig. 3 Surgeons using Google Glass in Operating theatres. (Khor et al. 2016)

contextual visualizations leading to lower mental stress and perceived pain. The immersive approach avoids distractions from the real-world to assist in the healing process. This ultimately leads to higher satisfaction among patients and speedier recovery (Kosa and Uysal 2018).

Journalism

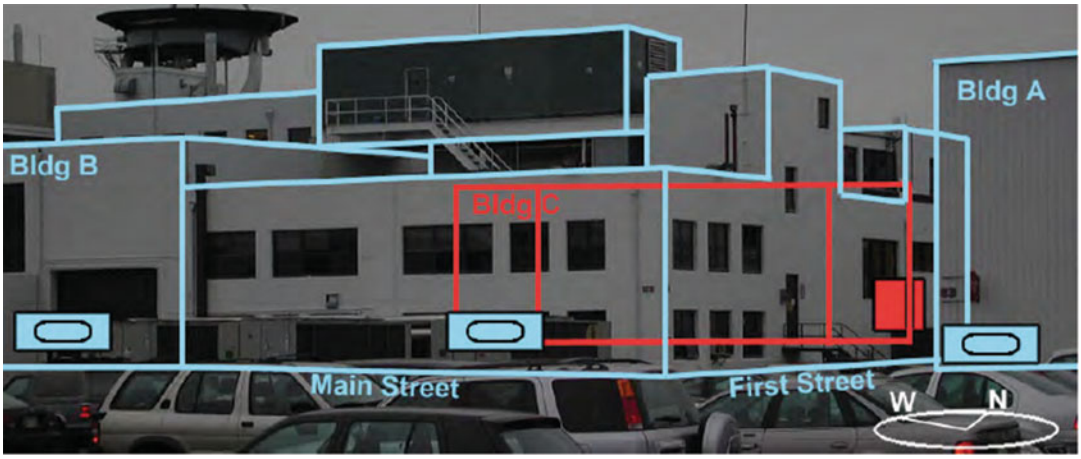
Interactive prints and immersive storytelling are revolutionizing the journalism industry. Augmenting the print media formats with digital content through AR and immersive storytelling makes news more effective and engaging. The immersive storytelling approach makes for more effective storytelling (via interactive media). The digital augmentation enhances the value of existing media such as print to make it more relevant for the users. It enables the users to get an easier transition from the existing medium to a new medium without losing context. Some of the limitations in this approach are lack of hardware availability, lack of tools for content creation, and lack of awareness among consumers (Pavlik and Bridges 2013).

Immersive storytelling is also experimented through virtual reality by many leading broadcasting and publishing companies such as *The New York Times* to deliver a first-person account of refugees during displacement due to crisis. These short experiences put a consumer in the middle of the action through 360-degree videos and evoke a strong sense of reality and empathy. The use of VR transforms the news from an account of data and information to an experience that heightened the learning as well as entertainment of the consumer. One of the limitations in this approach is shorter usage span of virtual reality due to headset issues, hence short, and bite-sized documentaries are popularly used for such experiences (Sirkkunen and Uskali 2016).

Defense

Military training uses virtual reality to simulate battleground and teach strategic tactics through interactive training for the forces. The VR simulations enhance both the navigation and coordination capabilities among soldiers. This method provides a more accurate representation of war scenarios and difficult situations than usual mediums due to its immersive environment and interactivity. The immersive simulations provide scalability and flexibility in training content (Livingston et al. 2011) (Fig. 4).

Augmented reality is used as a handy tool to disseminate real-time context-aware information in a military operation. This objective can be achieved through a head-mounted AR glass or a handheld device such as a smartphone. The usage of AR also helps in getting remote assistance or recreation of a specific environment, such as a demolished structure. It helps understand minor and vital details about the actual environment and make rapid decisions in combat situations. Navigation information is also delivered on an AR headset to guide the personnel making the experience seamless (Dodevska et al. 2018).



Immersive Visualizations Using Augmented Reality and Virtual Reality, Fig. 4 Military training simulation example, using Virtual Reality

Limitations

There are various technical as well as business challenges in implementing immersive visualizations using AR and VR. VR experiences are limited by the quality of the headset, quality of software applications, and interactivity issues. Standalone wireless headset suffers due to processing capability, weight, field-of-view, and battery life. High-end PC based VR headsets are difficult to set up and expensive. If not designed well, software applications can deliver a bad experience to users, including motion sickness. Interactivity is currently limited to the use of controllers and hand gestures, which are still evolving. Augmented reality experiences on AR glasses are limited by the design, size, weight, battery, and field of view of the headset. Smartphone-based AR experiences are widely used now. However, they do not provide rich, immersive experiences and interactivity. They suffer from issues such as dependency on a specific smartphone model, GPU capabilities of smartphone and smartphone hardware such as camera and display. Business limitations such as awareness about the technology, cost of adopting the technology, and consumer readiness are being researched for AR and VR implementation. Lack of maturity of the eco-system, such as availability of suitable hardware, software, and content, is also a challenge (Chandra and Kumar 2018; Leovaridis and Bahnă 2017; Porter and Heppelmann 2017).

Conclusion

Various applications of AR and VR provide better visualizations over traditional methods resulting in better decision making, cost savings for organizations, enhanced experiences for consumers, and many more. Immersive products provide an edge over the competition for businesses and enhance brand value, better stakeholder communication, and higher client satisfaction. At times it also facilitates cost reduction in specific scenarios. Though AR and VR as technology are beneficial and advancing at a rapid pace, there are some short-term challenges in implementing immersive visualizations. To overcome these challenges and make immersive visualizations effective, solution providers need to design products and services which provide the appropriate level of presence, interactivity, and immersion based on application. The human-centered design needs to be adapted for more human senses as AR and VR can make use of visual, aural, and spatial dimensions.

Cross-References

▶ Mindfulness, Virtual Reality, and Video Games

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Incremental Games

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Synonyms

Clicker game; Idle game

Definitions

Incremental game (otherwise known as idle game or clicker game) is a resource management game whose core mechanic consists of repeatedly performing a simple action, such as clicking a button, in order to gain currency. A prominent feature of incremental games is that after an initial time investment by the player, automated currency production is usually unlocked, allowing the game to continue in the background with little player interaction for extended periods of time.

Introduction

The year 2013 saw the rise to prominence of several early incremental games such as *Cookie Clicker*, *Candy Box!*, and *A Dark Room*. While displaying significant variation in terms of their aesthetics and storylines, all three relied on the same core mechanic of continuously clicking to accumulate currency (cookies, candies, or wood in the respective examples) in order to exchange it for other game objects and resources. The speed of accumulation would gradually increase and after a few initial interactions with the game, the accumulation process would become automated, enabling the player to leave the game running in the background and return to it occasionally to click for additional currency or spend it on upgrades, artifacts, and access to new types of resources (Deterding 2016).

These examples have inspired numerous subsequent games utilizing a similar dynamic, including *Clicker Heroes* (2014), *Plantera* (2016), and the educational *Rebuild the Universe* (2015). In the span of a few years, incremental games have become an established genre, even as multiple terms continue to be used to denote this genre, focusing on different aspects of it: incremental game, idle game, clicker game. Explaining the rising popularity of the genre, game critic Nathan Grayson pointed out that due to not demanding constant attention from the player, incremental games were easy to integrate into a daily routine and could be played even at one's workplace (Grayson 2015).

Origins

The idea of a game playing itself goes back to at least J.H. Conway's *Life* (1970), where the player sets up the initial configuration of the game in the beginning, but has no influence over the subsequent progression of the game (Björk and Juul 2012). More recently, *Godville* (2010) was a notable game to have entirely optional player interaction, casting the player as a god overseeing a world in which the nonplayer controlled hero adventures.

In the same year, *Cow Clicker*, a game that completely relied on repetitive clicking to progress was released by American researcher and game designer Ian Bogost. *Cow Clicker* is a Facebook game with a minimalist mechanic: the player clicks on a cow in order to obtain currency (clicks); however, they need to either wait for 6 h to click again or make a microtransaction to skip the waiting time. Bogost explained *Cow Clicker* as a satire of contemporary social games, which rely on the freemium distribution model and impose various limitations on the player in order to encourage them to make in-game purchases (Bogost 2012).

Despite its stripped-down gameplay and satirical nature, *Cow Clicker* gained significant popularity and inspired a number of similar games. Most notably, it became the inspiration for aniwey's *Candy Box!* and Julien Thiennot's

Cookie Clicker, which were among the earliest incremental games proper.

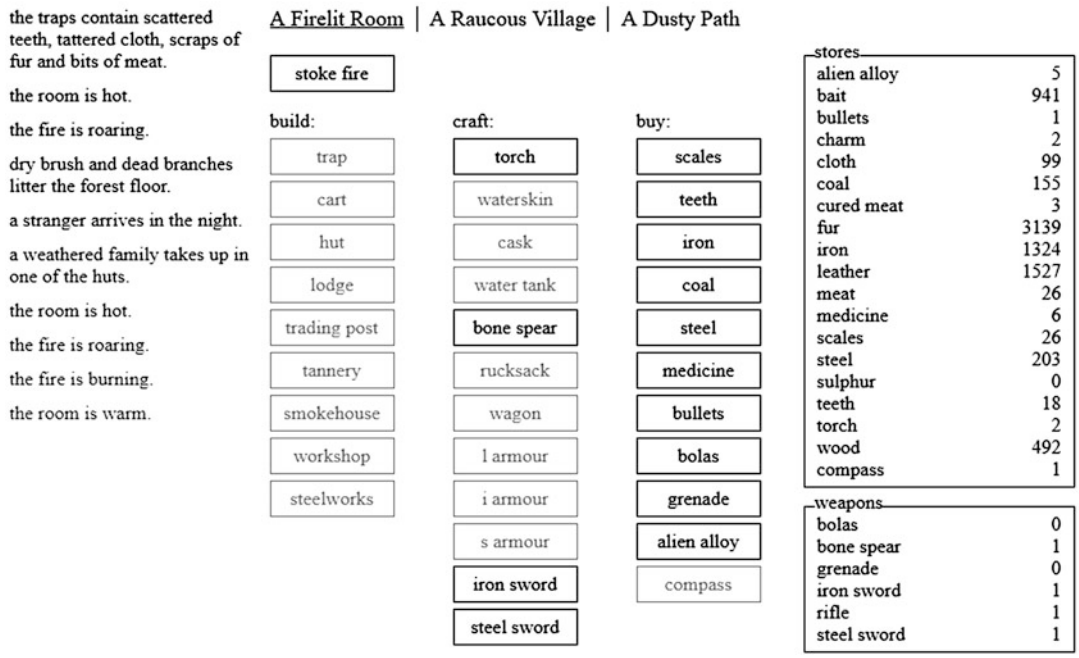
Structure

Incremental games share the following key features:

1. Their core dynamic is based on accumulating currency.
2. Initially, this is achieved by the player performing a certain repetitive action such as clicking.
3. After some player input, currency accumulation can be automated, enabling the game to "play itself" in between interactions with the player.
4. The game gradually increases in complexity, uncovering new features, resources, items, and locations.
5. This new content usually has to be unlocked by the player as it is not enabled automatically. Unlocking new content requires increasing amounts of currency.

This logic of increasing complexity means that beyond the core dynamic of incremental resource accumulation, idle games can rely on elements of different genres. For example, in *Candy Box!* and its sequel *Candy Box 2* the main currencies (candy and lollipops) are mainly used to unlock new locations and obtain items such as weapons and armor, which enables the player character to go on adventures and complete quests. This makes *Candy Box!* fundamentally a role-playing game. By contrast, *A Dark Room* features a much bigger variety of resources (wood, fur, cloth, meat, steel, coal, medicine, etc.) and mainly revolves around managing and defending a growing village, making it a strategy game (Fig. 1).

Some idle games, such as *Godville*, require no input from the player whatsoever. These are known as zero-player games, although it needs to be pointed out that just as not all incremental



Incremental Games, Fig. 1 Resource management in *A Dark Room*

games are zero-player, neither are all zero-player games incremental.

Significance

Incremental games "break with conventions and expectations regarding games" (Deterding 2016) and have led scholars to question existing definitions of video games, as these often revolve around player agency, which is limited in idle games (Khaliq and Purkiss 2015). Zero-player games in particular are problematic due to the absence of an obvious player figure (Ruffino 2016), leading Björk and Juul (2012) to argue that the idea of a game as something actively played by at least one human does not do justice to the complexity of both the notions of "game" and "player." In Deterding's (2016) words, while incremental games "started as an artistic inversion of game design conventions to demarcate the boundary of 'real' games," they ended up "expanding rather than delimiting the category."

The popularity of incremental games also reflects the evolution of the ways we use media. By allowing players to attend to other tasks while the game plays itself, incremental games accommodate the increasingly prevalent behavior of media multitasking (Bardhi et al. 2010). While incessant alternation between a variety of information sources was already conceptualized by Toffler as "blip-culture" (Toffler 1981), the advent of broadband Internet and powerful computers has furthered this process, leading to even shorter attention spans and more diverse media competing for audience attention. Incremental games, due to not demanding much player commitment while providing a sense of progress, fit this paradigm well.

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Independent Game

▶ Indie Game

Indian Perspective

▶ Strategies for Design and Development of Serious Games: Indian Perspective

Indie Game

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Synonyms

Independent game

Definition

An indie game is a game created by an independent team of developers, typically with limited resources, without a publisher or with no significant involvement in the artistic process on the publisher's part. Indie games are often experimental and/or employ a retro aesthetic. While the label is usually associated with digital games, it can also apply to analog (e.g., tabletop) games.

Overview

The term "indie game" became prominent in the mid-2000s (Garda and Grabarczyk 2016), although the concept of "indie" itself dates back to the 1980s (Hesmondhalgh 1999). "Indie" is a short form for "independent," indicating creative autonomy which indie producers are deemed to possess. While the concept originated in the music industry (Hesmondhalgh 1999), it gradually expanded to other spheres such as cinema (Newman 2009), fashion (Hauge and Hracs 2010), and, eventually, games.

The diverse indie media form a loose continuum of "indie culture," which "derives its identity from challenging the mainstream" (Newman 2009: 16) and generally embraces lo-fi aesthetics (Lipkin 2012). However, there is little systematic interaction between the different media within the spectrum of indie culture, with each of them having its own conventions and audiences which do not necessarily overlap.

In case of indie games, their rhetorical opposition to mainstream gaming has resulted in a tendency to use pixelated retro graphics and chiptune music evoking the look and feel of old video games. Notable indie games such as *Cave Story* (2005), *Fez* (2012), *Hotline Miami* (2012), and *Stardew Valley* (2016) can all be seen as homages to "classic" video games of the 1980s and early 1990s, even as they subvert or enrich the conventions of older games. Even the indie titles that do not directly utilize retro aesthetics tend to have a distinct visual style which looks minimalist compared to the hyperrealistic graphics of most mainstream games (at least in the West). This is the case for hand-painted platformer *Braid* (2008); the grainy, black-and-white *Limbo* (2010); the voxel-based 3D sandbox *Minecraft* (2011); and the lo-fi, full-motion video-based *Her Story* (2015). This approach to visual and sound design serves both a rhetorical and a practical function. On the one hand, it "is meant to invoke a type of authenticity <...> that marks it as distinct from the alleged realism" of mainstream games (Juul 2014); on the other hand, it enables indie developers to deal creatively with their limited budgets and skills (Lipkin 2012) (Fig. 1).

In addition to the purely aesthetic aspect, indie games also differ from mainstream big-budget titles insofar as the former are more open to experimentation and "aim to push the envelope of game design" (O'Donnell 2012). This experimentation can manifest in using innovative mechanics and having unusual plotlines and settings. For example, *Gods Will Be Watching* (2014) features an unlikely combination of point-and-click adventure with resource management (the resources being variables relating to the physical and mental well-being of its characters). *Braid* enriches the traditional puzzle platformer gameplay by adding the ability to rewind time; it is also revealed at the end that the hero's quest was a metaphor for the invention of the atomic bomb (Jagoda 2013). Text-based indie games by such authors as Anna Anthropy and Porpentine have dealt with queer identities and gender dysphoria, topics not commonly addressed by mainstream games. *That Dragon, Cancer* (2014) is an autobiographical indie game designed by Ryan and Amy Green to communicate their experience of caring for, and ultimately losing, a child diagnosed with cancer. These examples show the wide thematic range of indie gaming (Fig. 2).

Evolution of the Concept

When "indie games" first became an established term in the mid-2000s, it was often conceptualized in terms of the parameters of production such as budget, team size, revenue, and distribution model. Consider one of the early definitions of indie games in an academic paper: "Indie games are video games that have a small or non-existent budget and are often primarily available online or through friend-to-friend sharing" (El-Sattar

Indie Game, Fig. 1 Fez (2012) utilizes the retro platformer aesthetic, but subverts it by adding a third dimension

Indie Game, Fig. 2 Anna Anthropy's Dys4ia (2012) addresses an issue not commonly seen in digital games: gender dysphoria

2008). These definitions overlooked the temporal aspect of indie games: while "independent games" had existed for decades, designed by students in computer labs and bedroom developers in their homes, the narrower label "indie" is overwhelmingly used to refer to games developed in the twenty-first century (Garda and Grabarczyk 2016).

The circumstances of production are thus less central to defining indie games than the particular temporal and cultural context of their origin. The emergence of indie games was made possible by the availability of consumer-grade game engines such as *Game Maker*, *RPG Maker*, and *Unity* (Garda and Grabarczyk 2016), as well as the rise of digital distribution enabled by widespread access to broadband Internet and the shift to Web 2.0 (Parker 2013).

Moreover, as major corporate players, recognizing the market potential of indie gaming, started to publish games by indie studios and as crowdfunding platforms made it possible for indie developers to command large budgets, the understanding of what constitutes "indie" has also begun to shift. While it is still generally recognized that an indie game has to be developed by a small studio (which may, however, operate on a large budget and work with a major publisher), much of the focus is now on a general "indie sensibility" and indie aesthetic (Juul 2014). The shift to digital distribution platforms such as

Steam, where indie games and big-budget mainstream titles coexist within a single ecosystem, has rendered the circumstances of production nearly invisible, while highlighting the aesthetic feel and gameplay features which set indie games apart. The notion of an indie game was nebulous to begin with (Parker 2013), but now indie gaming seems to have mirrored the development trajectory of earlier indie media such as music and film: a shift from a movement characterized by relatively authentic opposition toward the mainstream to an aestheticized label largely incorporated into the very mainstream industry it once set out to challenge (Lipkin 2012).

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▶ Dōjin Game

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Indie Game Design

▶ Underground Design of Kaizo Games

Indie Game Developers

▶ Underground Design of Kaizo Games

Indigenous Knowledge for Mental Health, Data Visualization

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Synonyms

Data Visualization of Mental Health Issues; Mental Health of Indigenous Peoples

Definition

Indigenous is a common term used for First Nations, Inuit, and Métis in Canada. Indigenous peoples of Canada suffer from mental health issues more than their non-Indigenous counterparts. According to history, the delocalization of these people to remote places made them live independently, which strained their mental health (Kunitz 1996). Identifying the causes of mental health issues in Indigenous peoples and mitigating them is of dire need. One difficulty with understanding the main reasons for these mental issues is the existence of multiple contributing factors. These include different barriers that Indigenous peoples face in accessing healthcare because of colonization, cultural discontinuity, and racism and residential schools. On the other hand, Indigenous knowledge is still the main remedy for such kinds of mental problems in Indigenous communities. Representing the common mental problems between different groups of Indigenous peoples and the traditional way of life as a remedy for each specific group remains a challenge. Data visualization has evolved to create visual representations of data to help people quickly assimilate large amounts of information. Hence, data visualization can help to identify and assess factors relating to mental issues in different groups of Indigenous peoples.

Introduction

The significant mismatch between their traditional way of living and the current capitalism-based lifestyle plays a part in the increasing mental health cases among the Indigenous peoples. Surveys conducted on this issue show the deteriorating picture in terms of mental health in this community compared to their non-Indigenous peers (Nation n.d. 2010). There are various causes which have been linked to the deteriorating mental health condition of the Indigenous people. Cultural discontinuity, colonization, and obstacles in accessing healthcare all can contribute to this condition.

Data Visualization

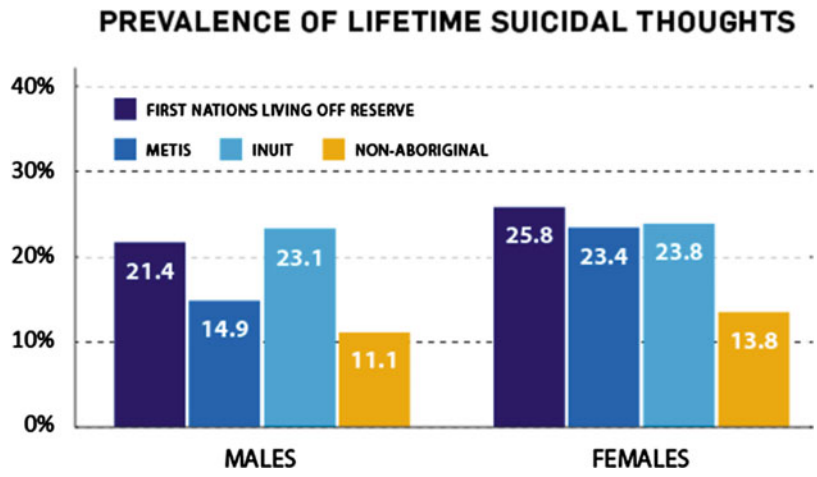
There have been various research surveys and studies conducted on the mental health of Indigenous people. These studies have provided a comparison between Indigenous peoples' mental health and their non-Indigenous counterparts' mental health. We can also see a gender-based comparison from some of the surveys. Figures 1 and 2 (Nation n.d. 2010) show the gender-wise comparison in Indigenous peoples. In Fig.1, we can observe that females have more suicidal thoughts than males and this is much smaller in non-Indigenous people than Indigenous people. We can also observe a higher suicide rate in Indigenous peoples in Canada, specifically among First Nations, compared to the non-Indigenous peoples (see Fig. 2), where the rate is higher for males than females.

Figure 3 (Nasir et al. 2018) represents the presence of common mental disorders among Indigenous Australians compared to the general population of Australia. We can see a similar trend of high mental health issues in the Indigenous population of Australia compared to the non-Indigenous people. In this Figure, the superscripts are indicated as the total Indigenous Australians % / total National Survey of Mental Health and Wellbeing, (NSMHWB) %.

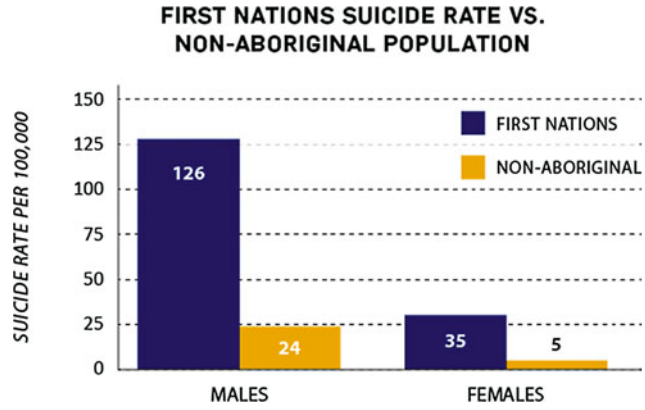
Barriers in Accessing Healthcare

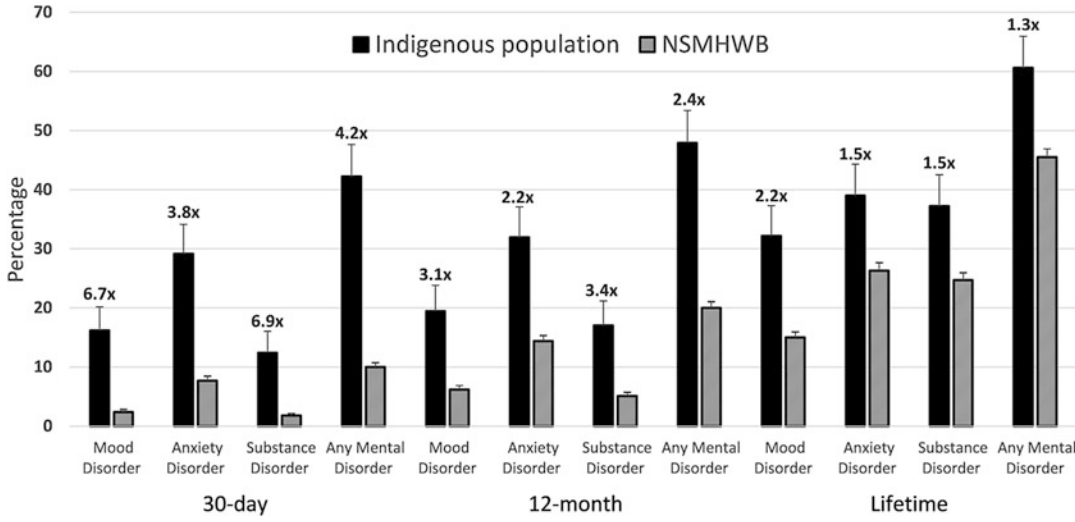
Barriers in accessing healthcare can be defined into three different categories, Proximal, Intermediate, and Distal barriers. Proximal barriers include geographical living places, lack of local educational institutions, and lack of presence of healthcare professionals that can negatively affect Indigenous peoples accessing primary healthcare (Nguyen et al. 2020). Intermediate barriers stem from a lack of employment opportunities and inadequate income. The distal barrier comprises colonialism, racism, and social exclusion. This hampers the involvement of Indigenous peoples in policymaking and accessing the proper mental healthcare (Nguyen et al. 2020). The effects of Colonization, Cultural Discontinuity, and Racism

Indigenous Knowledge for Mental Health, Data Visualization, Fig. 1 Comparing the prevalence of suicidal thoughts reported by First Nations, Métis, Inuit, and non-Indigenous people



Indigenous Knowledge for Mental Health, Data Visualization, Fig. 2 Comparison of suicide rate between First Nations and non-Indigenous people





Indigenous Knowledge for Mental Health, Data Visualization, Fig. 3 Standardized 30-day, 12-month, and lifetime prevalence of frequent mental disorders among Indigenous Australians compared with the general Australian population

and Residential Schools are still the most significant barriers that indigenous peoples are facing toward mental healthcare in Canada.

Colonization

The colonization of Indigenous peoples in Canada and its impact on their identities are significant when discussing mental health issues of the Indigenous community (Stout and Kipling 2003). The mental well-being and recovery of Indigenous peoples in Canada have always been tied to history, mainly about dislocation from their traditional lands and its consequences (Lavallee and Poole 2010). Several studies show how colonization impacted all aspects of Indigenous peoples' lives, including health, tradition, access to services, and equity, among others (Ristock et al. 2019; MacDonald and Steenbeek 2015). The colonization of Indigenous peoples in Canada and the historical impacts on their health, economic, and cultural experiences are well documented (Ristock et al. 2019). The results show that the source of low levels of mental well-being among indigenous peoples in Canada stems from the loss of traditional practices, breakdown of the family unit, and disconnection from the traditional culture.

Cultural Discontinuity

The cycles of family disruption, colonization, dislocation from traditional lands, and outlawing of spiritual practices among Indigenous peoples have led to many health and social inequities (Reading and Wien 2009; Halseth 2013). Rates of suicide, depression, and substance abuse are significantly higher in many Indigenous communities than in the general population (Lafrance et al. 2008). Colonization did not end with the creation of the new nation-state. In the past, Canadian government policies, including forced relocation of Indigenous peoples to remote regions, residential schools, and bureaucratic control, have continued to destroy Indigenous cultures (Kirmayer et al. 2007). This cultural discontinuity has been linked to a high rate of depression, alcoholism, suicide, and violence in many communities, with the most profound impact on youth. We see these traits in Indigenous peoples as they do not recognize the system compatible with their thinking (Firestone et al. 2015).

Racism and Residential Schools

The decentralization of Indigenous peoples from their natural habitats to remote locations and random social groupings forced them to adopt new ways of life. Relocating them was a part of the political and economic agenda. These policies served the non-Indigenous people with their interests, and explicit and precise forms of racism sustained this. These suppression efforts and harsh policies resulted from the thought that differentiated Indigenous culture as primitive and their people as uncivilized (Kirmayer et al. 2000). This prevented these people from practicing their religion and culture. They were even not permitted to participate in the democratic government. Therefore, as a means of getting rid of their culture and religion, residential schools were formed. Cultural assimilations were imposed on the Indigenous children by making it mandatory for them to get admitted to these schools. These all played a negative role in the mental well-being of Indigenous peoples and their children specifically (Nelson and Wilson 2017).

Common Mental Issues among Indigenous Peoples in Canada

First Nations adults experience a disproportionate burden of mental well-being and addictions. A study conducted in Hamilton on an urban First Nations population shows that among the 554 First Nations adults who participated in the study, 42% had been told by a healthcare worker that they had psychological and mental health disorders. Furthermore, 39% of them were suffering from high rates of depression, 34% had Post-Traumatic Stress Disorder (PTSD), 41% had suicide ideation, and 51% of attempts were reported (Firestone et al. 2015). PTSD might be linked to residential school attendants, abuse and family violence, family disruption by child protection services, and transgenerational trauma related to these, and other impacts of colonization (Menzies 2010; Corrado and Cohen 2003).

Another study has pointed out the high rate of mental disorders among Indigenous peoples (Tait et al. 2017), which states that suicide is a concern for many Indigenous communities in Canada. The rate of suicide among Indigenous peoples in Canada is higher than the national average. According to 2000 reports from the Canadian Institute of Health, suicides among First Nations youth aged 15 to 24 were about five to six times higher than non-Indigenous youth in Canada (Hossain and Lamb 2019). Indigenous peoples face a range of mental health issues at a higher rate than their non-Indigenous communities, and their life expectancy is also shorter (Frideres 1998; Waldram et al. 2006). The cause of this can be traced to higher rates of death among accidental death in young people and suicide. High levels of mental health problems have been documented in Indigenous communities (Nation n.d. 2010; Waldram et al. 2006). Mental health issues are directly affecting the social life and economic state of these people. The high rate of suicide, alcoholism, and violence can be both causes and effects of mental health problems. Suicide is one of the most dramatic indicators of distress in Indigenous populations. Epidemiological surveys undertaken on different communities of Indigenous peoples have pointed out the elevated rates of suicide among First Nations, Inuit, and Métis communities (Frideres 1998). These studies show that young people have a higher tendency toward suicide and attempted suicide. The results prove that assault on cultural identity besides low self-esteem is the main factor of this.

Indigenous Knowledge for Mental Health

Some remedies to these mental issues considering the traditional Indigenous way of life include Identity, Cultural Attachments, Languages, Community, Demographics, and Physical Activities and Games (Danto and Walsh 2017).

Identity

Natural healing for Indigenous peoples must include work around identity. The cultural identity of these people is one of the primary aspects that colonization has attacked and still affects them (Danto and Walsh 2017). The assault on cultural identity has played a significant role in the ill health of Indigenous peoples, and the spirit has been wounded. In that case, healing activities need to include rebuilding their individual and collective identity. This healing activity consists of a spiritual understanding of the individual and collaborative Indigenous culture.

Cultural Attachments

There is a relationship between cultural attachment and mental health among Indigenous peoples in Canada. Cultural attachment is assessed by involvement in traditional activities and Indigenous languages (Hossain and Lamb 2019). In addition, culture includes notions of how people react to situations, family patterns, and social interactions. Therefore, a new generation of practitioners is emerging who can combine local knowledge about health and healing with the most valuable aspects of psychology.

Language

Language is a primary conveyor of culture and people are most readily connected to their emotions and thoughts in their first language. Behavioral health scientists are assigning high importance to understanding a group's culture and traits in terms of treating mental health problems. On the other hand, language is one of the most vital components of culture and thus can impose great possibilities in understanding the psychology of a group of people. Various studies have explored language through its relationship to other demographic and cultural variables (Gonzalez et al. 2017). Studying different components of Indigenous language and focusing on the impact that they can impose on the mental health of the Indigenous population can be a means of bolstering the mental stability of this community.

Community

Despite the failures of the deinstitutionalization era in Canada, the community remains a central concept in mental health policy, clinical practice, and research. The idea of "community" is present in mental health policy, research, and clinical practice

in Canada (Gonzalez et al. 2017). The concept of community in treating mental well-being problems has a long history in the West, including thoughts about healing communities. The healing power of social relationships and the health impacts of the social and physical environment were central to this perspective. The optimism behind this should turn us toward community-based mental health services (Kirmayer et al. 2000).

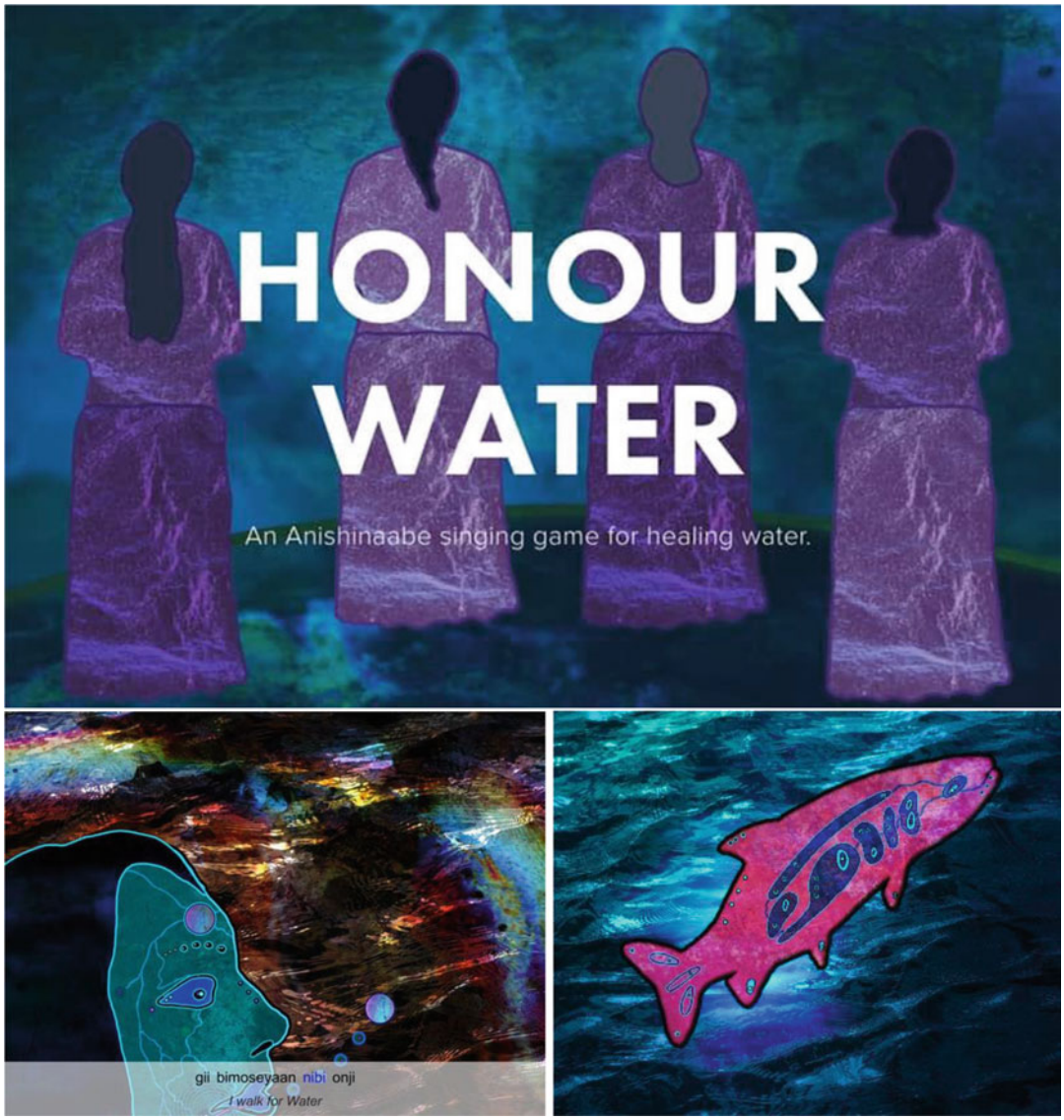
Demographics

When we address such critical issues as mental health, we should consider different needs and approaches for groups of people based on age, race, etc. For example, based on the references, there is a high rate of suicide among Indigenous youths, especially among First Nations, which is related to unemployment and economic issues (Tait et al. 2017; Hossain and Lamb 2019).

Physical Activities and Games

The physical activity program is the best way to understand Indigenous culture and identity. A high sense of belonging to the community and physical activity is associated with improved mental health and spiritual growth, specifically in older people (Bailey and McLaren 2005). Studies show that having the ability and motivation to belong in groups and doing physical activities with others contributed to the mental well-being of retirees (Bailey and McLaren 2005; Waldram et al. 2006). The sense of belonging may need to be facilitated to enhance mental well-being. The results indicate that higher levels of sense of belonging are related to lower depressive symptoms related to suicide ideation (Lavallée 2007). Traditional ways of hunting and gathering foods can help the Indigenous peoples improve their mental well-being. It is worth mentioning that some healing ceremonies can improve their mental well-being, including Pipe Ceremony, Wedding Ceremony, Naming Ceremony, Sweat Lodge, Full Moon, Pow Wow, and Smudging. One of the appropriate ways to increase self-esteem and happiness among children is by engaging them in games. It refers to common physical activities/games that Indigenous and non-Indigenous children can play together, which improves mental well-being in Indigenous children and introduce their culture to non-Indigenous peoples (Dubnewick et al. 2018). Community-based participatory research was conducted in 2018 (Dubnewick et al. 2018) to better understand how participation in traditional games can enhance the sport experiences, and further the mental well-being of Indigenous youth. Eight Indigenous youth (14–18 years) and 10 adults living in various communities in the Northwest Territories, Canada, participated in either a one-on-one interview or a group interview. Data were analyzed using an inductive content analysis approach, and findings suggest that participating in traditional games can enhance the sport experiences of Indigenous youth by (a) promoting cultural pride, (b) interacting with Elders, (c) supporting connection to the land, (d) developing personal characteristics, and (e) developing a foundation for movement. Participating in activities such as traditional games, which incorporate traditional ways and Indigenous values, may provide a unique opportunity to enhance the sport experiences of Indigenous youth. That being said, traditional games can provide Indigenous peoples with the opportunity to engage in sport within an environment that reflects their cultures (Heritage 2005). Traditional games, including Inuit games (e.g., two-foot high kick) and Dene games (e.g., stick pull), are strongly influenced by life on the land whereby such games optimize the endurance, strength, and agility that were, at one time, necessary for survival (Heine 2006, 2007). Traditional games were central to the lives of Indigenous peoples (Heine 2013).

However, with European colonization and the "broader assimilative agenda in Canada," there was an effort to eradicate the traditional sports and games of Indigenous peoples. More recently a number of computer game development companies have created new computer games while advocating for technology across the Indigenous world. For example, Honour Water is an Anishinaabe singing game for healing water which is developed by Pinnguaq, a Nunavut and British Columbia based corporation (see Fig. 4). At the root of their mission statement is the embracement of technology as a means of unifying and enabling both Indigenous and non-Indigenous cultures.



Indigenous Knowledge for Mental Health, Data Visualization, Fig. 4 Screenshots of the Honour Water game on App Store- Apple Inc. (Courtesy of Pinnguaq Technology Inc. Songs by Anishinaabe elders and Sharon Day sung by the Oshkii Giizhik Singers pass on teachings about water in Anishinaabemowin)

More research would be required to evaluate the success of such computer games towards this mission.

Conclusion

Colonization and relocation of Indigenous peoples in Canada to remote places affected different aspects of their lives such as language, culture, traditional activities, and mental well-being. Similar to Indigenous populations of other parts of the world, Indigenous peoples in Canada have suffered adversaries leading to a very different way of living. Declining population due to epidemics of infectious diseases, religious conversion, enforced colonization, and separation from family members have all played a part in the changed

lifestyle of Indigenous peoples. The traits and nature of Indigenous groups are different and should not be generalized in terms of understanding their culture to treat mental problems. This will help us to have a better understanding of their needs and thoughts. Equity of well-being for the Indigenous population is vital for constructing an equal and just society. To achieve this goal, an analysis of the history and its impact on the Indigenous mental well-being, such as the common mental issues and barriers to accessing healthcare, should be studied and visualized based on the main factors, including Colonization, Cultural Discontinuity, and Racism and Residential School. Indigenous knowledge is a way of understanding their needs and improving their mental health around Identity, Cultural Attachments, Languages, Community, Demographics, and Physical Activities.

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Indigenous Language Revitalization with Stories and Games

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Synonyms

First nations; Mobile applications; Revival of Indigenous languages

Definition

According to Statistics Canada, numerous Indigenous languages are spoken in Canada. However, the number of speakers of these languages is declining due to historical and social factors. Efforts are underway to recognize the importance, preservation, and revitalization of these languages. A careful evaluation of the related challenges, potential solutions, and benefits is essential.

Introduction

The technological revolution has transformed almost every aspect of life including novel educational systems. Digital language learning technology has revolutionized language learning within only a few decades and it leads to becoming a prominent mode to study and learn a new language. It is no longer necessary to browse through heavy bidirectional dictionaries and textbooks as a tool to learn a new language. The availability of language data, the increasing demand from language learners, and greater access to native language speakers have enabled many innovations in the fields of linguistics and language learning. However, it is far more recent to apply these resources and technologies to the Indigenous languages of people from around the world. Traditionally, language learning resources and technologies have been built mainly with the purpose of teaching language aimed at tourism, business, and employment. Indigenous language technologies, on the other hand, are primarily aimed at language documentation, revitalization, and reclamation. As a consequence, since Indigenous languages possess unique characteristics, the current language technologies and methods may not be directly applicable in this context as a straightforward process. Indigenous language technologies have received increased support in Canada over recent years. However, greater opportunities require more discussion about what these technologies can look like and how they will be implemented in practice (Brinklow et al. 2019).

Background

Individuals use language as a means of communication, education, social interaction, and development. That being said, language is also deeply related to identity, cultural heritage, tradition, and memory. Hence, when a language is lost, cultural heritage and identity are lost and may be lost forever or not be recoverable at all (Oladimeji et al. 2020). According to the United Nations Educational, Scientific and Cultural Organization

(UNESCO), it is estimated that at least 40% of 7000 languages used worldwide are at risk of extinction. The use of Indigenous languages in Canada has been suppressed for generations due to the history of restrictive colonial policies. Many Indigenous languages are presently endangered since most of them are not taught or used in schools, universities, industries, and business. The year 2019 was designated the international year of Indigenous languages by the United Nations, to emphasize the importance of revitalization of Indigenous languages at the regional, national, and international levels. In Canada, one of the items listed in the Truth and Reconciliation Commission's Call to Action was that the federal government should acknowledge Indigenous languages as an inherent right of Indigenous peoples and support to "preserve, revitalize and strengthen" these (Justice Laws 2019). In the 2016 census in Canada, nearly 70 Indigenous languages were reported. There are tens of thousands of speakers for several of these languages, while others have a few tens or hundreds of mostly elderly speakers (Anderson 2018). Thus, Indigenous languages can be said to be endangered. Based on 2016 statistics, 260,550 Indigenous peoples can speak an Indigenous language well enough to conduct a conversation (O'Donnell and Anderson 2017). On the other hand, Indigenous peoples' language and culture are dependent on each other since their cultures are rooted in oral traditions. By oral tradition, Indigenous peoples transmit their epic poems, prayers, speeches, spiritual teachings, songs, stories, and history. The oral tradition usually transfers culture from one generation to the next through elders or older people. The oral tradition makes the importance of maintaining and revitalizing Indigenous languages more apparent.

The study in this entry suggests a user-centered application for the Indigenous Education and Cultural Services at Ontario Tech University that supports Indigenous languages. Ontario Tech University is on the Traditional Territory of the Mississaugas of Scugog Island and the territory is covered by the Williams Treaties. The Mississaugas is one of the branches of the largest Indigenous groups in Canada which is known as the Ojibwa Nation. Around 1700, the Mississaugas of Scugog Island moved from their previous home north of Lake Huron into southern Ontario. The Ojibwe language is the most prevalent Indigenous language in the area, which serves as a focus of this study (O'Donnell and Anderson 2017).

The authors of this entry are not Indigenous peoples and acknowledge that they are not in a position to speak to the values or views of the Indigenous communities or their culture. This entry aims to offer a view of possible options for designing a mobile app for learning Indigenous languages. It is important to mention that elders can always provide more valuable guidance on how to meet the needs of their communities.

Literature Review

In 2019, Morgan Cassels and Chloe Farr published a review paper on mobile applications for Indigenous language (Cassels and Farr 2019). The authors discuss whether mobile apps can strengthen language revitalization efforts and debate the advantages and disadvantages of using apps as a medium for Indigenous language learning. Furthermore, 32 apps are examined and concluded that some apps focus on a specific goal or strategy while others offer a wide variety of different activities, such as stories and games. According to the authors, most Indigenous language apps provide users with a mixture of dictionary features, common phrases, vocabulary exercises, games, quizzes, and cultural content.

In another study, Oladosu Oladimeji et al. examine how technology can play a role in revitalizing culture and language in acute areas (Oladimeji et al. 2020). They notice that individuals must show interest in the language to learn it. A new way of learning the Yoruba language is presented by using mobile games to arouse the interest of students and thereby further promote and revitalize the Yoruba language and culture. A survey questionnaire was used by developers to assess the quality of the mobile application that was installed by participants who explored

the application. The games are ranked based on some metrics including extensibility, security, ease of use, and whether the user finds it interesting to learn Yoruba after playing it. According to their result, 76% of respondents found the game easy to use, 70% rated it as sufficiently extensible, and 90% found it gratifying to learn Yoruba after playing the game. It will be an entertaining and interesting method of motivating people to develop an interest in learning the native Indigenous language individually or in groups.

In a more recent work, the National Research Council of Canada (NRC) conducted a project known as "Indigenous Languages Technology (ILT)" (Kuhn et al. 2020). Phase I of this project allocated $6 million in funding by the Government of Canada in March 2017 and Phase II of the project is currently underway. The ILT's project aims to produce software that will facilitate Indigenous language preservation and revitalization efforts throughout Canada. The authors mention that several technologies were developed in response to community demands, and the project was split up into subprojects including text-based and speech-based components. The authors indicate that a significant challenge in their project was in building respectful relationships with communities.

Issues

Many institutional and societal factors have contributed to the decline of Indigenous languages in Canada, such as the development of residential schools and the Indian Act. Assimilation of colonial culture was the explicit purpose of Canada's residential school system. This aim was achieved if Indigenous language and culture were not taught to generations of Indigenous children. These schools housed children forcibly taken from their homes. If they spoke their mother tongue there, they were punished. Thus, generations of Indigenous peoples turned away from their heritage and language. In 1996, after over 150 years, these schools were fully closed. As a result of the residential school system, many Indigenous peoples may still feel a sense of shame to speak their language (Brinklow et al. 2019).

English and French are the two official languages of Canada. According to the 2016 census, it reported that more than 95% of employees used English or French at work regularly (Lepage and Corbeil 2017). Furthermore, English and French are used in schools, universities, business, etc., and can be considered the languages of success. By viewing this reality, it becomes clearer why some Indigenous peoples are reluctant to learn or speak their language.

Finally, there is no doubt that an aging mother tongue population contributes to the extinction of Indigenous languages. If the Indigenous languages are not taught to the next generation, they will disappear.

Possible Solution

Several efforts are underway to prevent Indigenous languages from extinction. With the help of technology, Indigenous languages can be revived, reclaimed, and supported (Oladimeji et al. 2020). In this paper, designing a mobile game language-learning application based on Indigenous culture with Indigenous community involvement, especially among elders, is suggested.

The Importance of Connecting with the Elders

Seeking support from the elders is crucial to ensure language instruction is consistent with the standards and the dialect of the community. The language and Indigenous peoples' lives are connected (Desmoulins et al. 2019).

Advantages of Mobile Game Apps for Language Learning

A mobile device can be an excellent tool for learning a language due to several reasons. First, the portability of mobile apps is one of the main advantages. It allows users to use their free time more productively. Second, a mobile app may be helpful to those who are uncertain about how to pronounce vowels correctly or are afraid of being mistaken. Third, a great advantage of mobile apps is that they give learners the choice of owning the learning

tool, rather than enrolling in expensive classes or using traditional study materials. Fourth, mobile applications can provide a fun and entertaining learning experience (Cassels and Farr 2019).

The popularity of video games and mobile games has grown considerably in recent years and their popularity among young people makes them a potentially useful tool in education (Oladimeji et al. 2020). Hence, game apps can be a valuable tool to revitalize Indigenous languages. Score points of players in a certain mobile application game could be a measure of learning. It can enable the users to understand the reasoning behind obtaining a low score and utilize it to have a better learning experience following repetition (Godoy 2020). Games that use a learning scenario-based approach involve the gamers in a problem-based setting to solve problems. Hence, the players will be required to make decisions about integrated questions, experiment with the options offered, interpret feedback, and adapt to new learning methods for new insight and skill development (Godoy 2020).

General Challenges

Indigenous language technology development will be faced with many challenges and problems. Here, there are two distinct types of challenges, one associated with the Indigenous languages and another one related to mobile game apps.

Challenges Regarding Indigenous Languages

There are several reasons why dealing with Indigenous languages can be challenging. Some of these challenges are listed below (Littell et al. 2018).

- The morphological complexity of Indigenous languages is typically very high.
- Often, a single word conveys the meaning of what might otherwise be a complete clause in English or French.
- It is challenging to get a digitized text or sound available for training in most Indigenous languages.
- There are various dialects within Indigenous languages. Still, there is a lack of references to whether the orthographic standards were developed for all dialects or if only one dialect is represented in the sources and articles.
- There are several orthographies used to write the Indigenous languages. Even though the orthographic union (unification) of the language leads to a general improvement, there are still significant differences between languages based on their location or age.

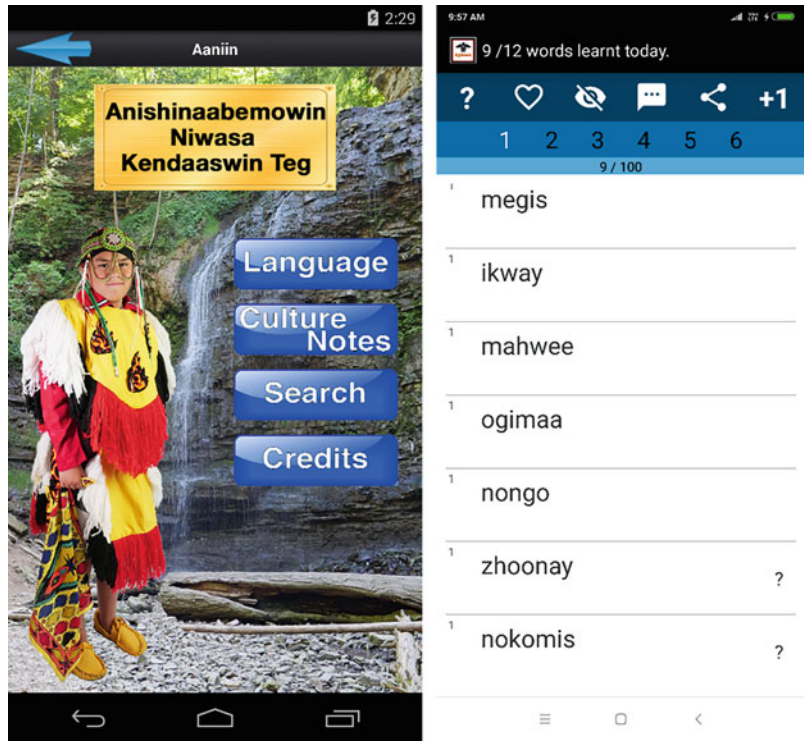
Challenges Regarding Mobile Game Apps

In addition to many other uses, mobile game apps can be useful tools for language revitalization efforts. Indigenous language learning apps can be effective when language acquisition with cultural themes is combined. Hence, it is vital to consider how it can be designed pedagogical activities and tools in a manner to respect the culture, community, worldview, protocols, and physical environments of Indigenous peoples (Cassels and Farr 2019). A technology-based community initiative must deal with the rapid pace of technological change. It is also common for apps to be updated periodically, like other software products. Those who want to use the app must have a device that is compatible with the current version. This compatibility issue may make it difficult for individuals to keep up-to-date devices since maintaining their devices may be expensive (Cassels and Farr 2019).

Games

To revitalize Indigenous languages, many efforts are being made to use traditional games or mobile games. These games are helping to keep these languages alive and provide a valuable resource for those who would like to learn and preserve these precious cultures. The following are some examples of mobile game apps for indigenous languages in Canada; see Fig. 1.

- Anishinaabemowin Niwasa (Thornton Media, Inc. 2019): This game is designed to teach players the Anishinaabe language. It features



Indigenous Language Revitalization with Stories and Games, Fig. 1 Images from mobile game app for indigenous languages in Canada: Left: Anishinaabemowin Niwasa (Thornton Media, Inc. 2019); right: Beginner Ojibwe (shotgun. experiments 2018)

a series of mini-games that help players learn vocabulary and grammar in a fun and interactive way.

- Beginner Ojibwe (shotgun.experiments 2018): This app is designed for those new to the Ojibwe language or those who are enthusiastic about learning it. The app follows a "word of the day" approach, allowing users to select up to 12 words per day to learn. It is meant to be a straightforward introduction to the language.
- Ojibway (Baxter 2017): This app teaches users the Ojibway language using professional-quality audio, pictures, and syllabics. It covers important aspects of the Ojibway culture, including history, geography, famous people, and treaties. The app also teaches common phrases, pronunciation, and syllabic writing. It provides comprehensive information about the Ojibway people, including their lifestyle, history, and notable figures.
- Cree Language (GNWT Official Languages 2016): This game teaches players the Cree language through a series of word puzzles and challenges. It also includes cultural teachings and stories to help players gain a deeper understanding of the Cree people and their traditions.

Such games provide a fun, engaging, and accessible way to learn indigenous languages in Canada, and they protect these precious languages for future generations. They are, however, typically only available for a single operating system or platform, and their static nature can lead to them being outdated.

Design Considerations

Mobile game apps can help revitalize the Indigenous peoples' languages if children and youth will be taught to speak the language using these. However, to be accepted by its audience, the mobile game application has to be entertaining and well-designed. The user interface, fast loading time, high performance, and compatibility with different mobile platforms are key factors here. If a

mobile game app did not meet these criteria, it would barely succeed.

The term cross-platform in mobile game applications refers to the fact that users of different hardware or operating systems can play the same game simultaneously. Therefore, it is very important to have a mobile game app that can run on Android, iOS, and other common operating systems and hardware.

One of the best ways to develop a cross-platform app is by using game engines. Game engines are the core software needed for a game to run properly. It is possible to have various versions of a game app for different platforms after developing a game using a game engine. Developing a cross-platform mobile game app using a game engine to teach the Ojibwe language would be an excellent idea.

Due to the need for an Ojibwe language-learning mobile app to be scenario-based, some stories from this nation can be used in the process of app design and development. Concepts such as treaty rights, tribal sovereignty, wild rice, and spearfishing are a few examples that can help mobile game apps to be better adjusted to the community's culture.

Conclusion and Discussion

In conclusion, scenario-based mobile game applications can play an important role to promote and preserve Indigenous languages and cultures by honoring the Indigenous way of life. It is also clear that interaction with the Indigenous community, in particular with the elders, and receiving feedback from them can enable an application to be suited to their needs. Hopefully, this will help to promote the awareness of the Indigenous community, especially the new generation and youth, about their language.

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Inductive Learning

▶ PBL-Based Industry-Academia Game Development Education

Industrial Robot Augmented Reality

▶ Augmented Reality for Human-Robot Interaction in Industry

Industry 4.0

▶ Design Framework for Learning to Support Industry 4.0

Information Presentation Methods

▶ Information Presentation Methods in Virtual Reality

Information Presentation Methods in Virtual Reality

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Synonyms

Information presentation methods; Serious games; Tutorials; Video games; Virtual reality

Definitions

Virtual Reality: A model of reality with which users can interact using senses such as sight, sound, or touch.

Immersive Virtual Reality: A type of virtual reality in which the user's complete view is surrounded by the synthetic environment, as if they had stepped inside the virtual world. It is usually distinguished by the high level of immersion and interactivity offered.

Information Presentation Method: The way information is conveyed to users in virtual world. It can be in various forms such as animation, video, visuals, text, audio, and pictographs.

Serious Game: A video game with a purpose beyond entertainment such as teaching users a new skill or training users to improve their existing skills on a subject.

Introduction

After early 2010s with the launch of more affordable and higher fidelity new generation headsets, virtual reality (VR) has become a very popular medium for various areas such as games, training, and rehabilitation. Despite its increasing prevalence and proven success in many topics, there are still a lot of unknowns and unexplored areas related to virtual reality. One of these areas that has not been much explored yet is information presentation methods in virtual reality. Information presentation is important in the sense that it informs users about what they need to do in the virtual world. Virtual reality offers a high degree of visualization, but it is unknown whether three dimensional instructions work better than two dimensional, for example. If not prepared appropriately, information presentation may affect user experience negatively and cause frustration in users. Thus, information presentation method is an important aspect of virtual reality. In this entry, researches conducted in this area so far are presented along with future directions and conclusions.

Dynamic and Static Information Presentation Methods in VR

Several studies that had conducted in the early years of virtual reality stated that dynamic information presentations such as animations were more beneficial in terms of cognitive aspects, than static methods such as text and pictures (Levie and Lentz 1982; Park and Hopkins 1992;

Rieber 1990). Some following studies contradicted with these prior findings, concluding that static methods might have been as effective as dynamic methods (Hegarty 2004). The reasoning behind this was that although the dynamic methods might have had advantage over static ones in terms of visualization, they also had associated pitfalls such as demanding continuous attention of the user and presenting information only for the duration of the included motion. In this sense, the static information presentation methods were available for viewing as long as the user wanted to, since they were not associated with any movement duration constraint. The required cognitive load for viewing also was lower, since they did not include any dynamic elements. A third realm of studies followed these two contradicting views, which combined static and dynamic information presentation methods and examined the effects on user experience. The researchers found out that it resulted in disjointed understanding, as some participants were not able to figure out how to integrate the two or when to focus on which one (Ainsworth et al. 2002; Anzai 1991). As a remedy, a following study suggested that having the user actively participate in the integration of picture-based and symbolic information presentations provided better user experience and increased understanding (Bodemer et al. 2004). The importance of information presentation method not only lies in the level of understanding it provides the users but also its effects on the production costs. Dynamic methods such as animation and videos are costlier and more time consuming to produce, whereas static methods such as pictures or text are usually less costly and less time consuming. Hence, it is important to understand which information method in virtual reality would provide the best user experience while being cost and time effective at the same time.

Tutorials in Serious Games

Ushaw et al. looked at the video game industry and studied which of the best practices could be adopted from commercial video games to serious games with a health focus (Ushaw et al. 2015). The best practices that were found to be suitable for adopting were: brief in-game instructions that are on-screen (not on a manual or a printed out document) and readily available to the player for the duration they like to view them; using prerecorded videos of required in-game actions and using these recordings as an in-game tutorial. Greyling and Calitz studied on developing a computerized multimedia tutorial system they named "ACCUTUT," which aimed to train prospective higher education students in using computerized admission test user interfaces effectively (Greyling and Calitz 2003). In this system, the following instruction methods were used: written, verbal, and simplistic icons (brief pictures). Researchers found out that using such assistive information presentation methods instead of requiring students to read large segments of text improved user experience and eliminated several interface problems while taking these admission tests.

Spatial Information in Information Presentation

To assist users with understanding information, some previous studies explored the use of spatial information in VR systems. Bowman et al. looked into whether using spatial information presentations inside a virtual zoo would stimulate learning and comprehension in participants or not (Bowman et al. 1999). In the virtual zoo system, the following information presentation methods were used: verbal, text, a few accompanying images (only for complex content), and audio annotations that were triggered automatically if the users were close to them. Although not evaluated in isolation, these assistive information presentation methods were observed to increase users' understanding of the layout and design on the virtual environment. The virtual zoo experience enabled students not only to learn the presented information directly but also to understand the material better as compared to traditional teaching methods. Likewise, Ragan et al. also explored effects of supplementary spatial

information on user experience (Ragan et al. 2012). Written and symbolic information presentation methods were used in the VR system and participants' performance on learning-based activities were measured. In one version, information was presented directly to the participants in the virtual environment, and in the other version, information was wrapped around the participant on surrounding displays. Experiment results showed that spatial information presentation provided improved memory scores whereas no improvements were observed for higher level cognitive activities, such as critical thinking.

Commonly Used Information Presentation Methods in VR Systems

Unless they rely solely on human tutors who will explain the users how to use the system and what tasks to perform in it, almost all VR systems include some form of instructions. In this subsection, we present a compilation of recent VR systems and the information presentation methods they utilized. These studies did not focus on exploring effects of instruction methods in VR on user experience; however, observing the common choices of instruction methods chosen to be used by the recent studies may shed light on understanding information presentation methods better.

Oliveira et al. utilized text-based instructions in their VR system for industrial equipment maintenance training (Oliveira et al. 2007). Galvan-Bobadilla et al. used several different instruction methods (animated, written, and verbal) in the VR system they developed for training users on maintenance of underground power distribution lines (Galvan-Bobadilla et al. 2013). Stinson and Bowman utilized text-based instructions in their VR system that aimed to train athletes on handling high-pressure situations (Stinson and Bowman 2014). Carlson et al. chose to include prerecorded video-based instructions in their VR training system for assembly tasks (Carlson et al. 2015). Chittaro and Buttussi included text-based instructions and very brief pictures in their VR serious game for aviation safety training (Chittaro and Buttussi 2015). Aggarwal et al. also utilized text-based instructions and very brief pictures for presenting information in their VR laparoscopic surgery training curriculum development studies (Aggarwal et al. 2009). Corato et al. chose to include real-time animation overlays along with text-based on-screen instructions as information presentation methods in their VR system for training surgery staff on hand-washing procedures (Corato et al. 2012).

Conclusion

Although some previous studies have examined effects of information-presentation methods on user experience in VR, there are still no well-established design principles recommending which method works best for different aspects such as entertainment, training, learning, memorization, or retention. More studies are needed to identify effects of information presentation methods on user experience for improved VR experiences.

Cross-References

- ▶ Accessibility of Virtual Reality for Persons with Disabilities
- ▶ Cognitive Psychology Applied to User Experience in Video Games
- ▶ Gamification and Serious Games

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Information Visualization

▶ Cognitive Processing of Information Visualization
▶ Immersive Visualizations Using Augmented Reality and Virtual Reality
▶ Mixed Reality and Immersive Data Visualization
▶ Scalable Techniques to Visualize Spatiotemporal Data

Innovative Technology

▶ Exploring Innovative Technology: 2D Image Based Animation with the iPad

I

Integrating Virtual Reality and Augmented Reality into Advertising Campaigns: History, Technology, and Future Trends

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Synonyms

Advertising; Augmented reality; Campaign; Virtual reality

Definitions

Augmented reality (AR) is a simulated, but enhanced, reality that combines both computer-generated virtual and real-world data to enable users to perform real-time interactions with digital graphics, imagery, and objects, in a seamless way and with an illusion of these layers of information coexisting in the same space.

Mixed reality (MR) refers to an umbrella concept from the reality-virtuality continuum to allow users to experience the key efficiencies of both AR and VR technologies. This technology analyses users' surrounding real-world environment before producing a digitally generated graphical reality.

Virtual reality (VR) is an assembly of technologies that offer immersive, interactive, and information-rich experiences when users are able to interact with objects and realities in a computerized, simulated, real-time 3D virtual environment by employing their senses and skills.

Introduction

A recent research report by the International Data Corporation (IDC) (2017) forecasts that the global revenue for both augmented reality (AR) and virtual reality (VR) will reach $13.9 billion in 2017, a dramatic increase from $6.1 billion in 2016. The compound annual growth rate of AR and VR will reach $143.3 billion in 2020 (IDC 2017). By 2020, growth in the online retailing and digital game sectors will be the top two applications of AR/VR technologies (IDC 2017). As a result, AR/VR campaigns have been accepted into major advertising awards. For example, the Creative Arts Emmys granted Fox's *Sleepy Hollow Virtual Reality Experience* (https://www.youtube.com/watch?v=peFGMwVQXL0) an interactive media award for its creative achievement (Giardina 2017).

Digital advertising plays a particularly significant role in the growing electronic and mobile commerce markets. Its sheer size has prompted advertisers to experiment with AR/VR technologies (Metz 2015a, b). Past advertising literature has observed that AR/VR technologies are able to offer the benefits of immersive storytelling, product demonstration, and emotional arousal to engage consumers in advertising and marketing campaigns, according to Interactive Advertising Bureau (IAB) (Klie 2016). Furthermore, the rapid diffusion of smartphone devices also creates a ubiquitous communication environment that allows consumers to constantly interact and engage with advertising campaigns (Persaud and Azhar 2012). The social media population now accounts for 37% of the world's population or 60% of Americans (Jorner 2017). The pervasive presence of social media further prompts advertisers to take advantage of the opportunities in integrating both platforms (Swant 2017a). For example, Facebook debuted its Facebook Spaces AR platform to offer its users AR experiences through an Oculus Rift headset (Swant 2017a).

This entry will go over the definitions of AR and VR, discuss the technological developments relevant to the advertising industry, examine major determinants in their adoption by advertising practitioners, and provide AR/VR campaign examples to demonstrate their potential.

Virtual Reality (VR)

VR is defined as a computer-generated and simulated environment in which users are immersed in a virtual environment to experience the presence of other objects or realities through interaction with them (Heim 1998; Hsu 2017; Kerrebroeck et al. 2017). VR technologies have been used in military training as early as 1995 (Kerrebroeck et al. 2017). Recent VR applications range from aviation, medical (Claudio and Maddalena 2014; Hsu 2017), advertising (Bazilian 2017a, b; Johnson 2017a, b, c, d), marketing (Heine 2017; Javornik 2016), etc.

As an emerging media platform for advertising practitioners, VR is characterized with three key attributes, or "Three I's": immersion, interactivity, and information intensity (Claudio and Maddalena 2014, pp. 2–3). First, VR users are fully immersed in a computer-mediated environment through VR headsets such as Sony PlayStation VR, HTC Vive, Oculus Rift, Google DayDream View. Scholars have found that immersive VR experiences often strongly affect adults' attitudes, behaviors, and thoughts (Bailey and Bailenson 2017). As a psychological state that is often experienced by VR users in the virtual environment, immersion is considered to be the most important aspect of VR technologies (Kerrebroeck et al. 2017).

Secondly, interactivity refers to the human-computer interactions made possible by VR gadgets such as VR helmets that offer high 3D sights and sounds, and high-resolution quality, as well as motion-tracking hardware and software to interact with the virtual world (Claudio and Maddalena 2014). As defined by Steuer (1992), this concept refers to "the extent to which users can participate in modifying form and content of a mediated environment in real time" (p. 84). Interactivity of VR campaigns thus enables consumers to experience individualized and customized advertising contents. Thirdly, VR also provides ample information and functionality that involve all human senses (such as hearing, kinematic, proprioceptory, and vision) to allow users to meet their entertainment and hedonic gratifications (Kerrebroeck et al. 2017).

A VR system is composed of several different technologies that include (1) a graphic rendering system; (2) gloves, trackers, and user interface to detect and input users' movements; (3) output devices to facilitate aural, haptic, and visual interactions in the VR environment; (4) a software to model virtual objectives and to construct databases; and (5) a system to deliver VR sensory stimuli such as visual display technology to offer users interactive and immersive experiences (Claudio and Maddalena 2014).

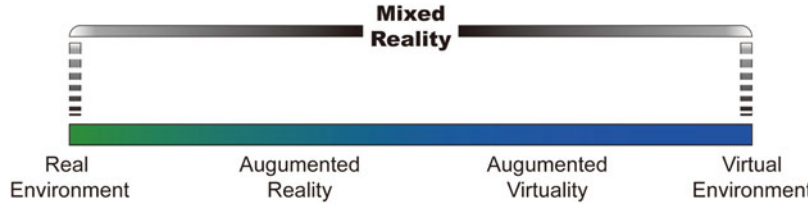
Advertising practitioners who would like to take advantage of the potential of VR technologies are still faced with several challenges. First, the potential of VR technologies in advertising lies in their diffusion and the attractiveness of related applications. According to a survey of 811 American adults by YuMe, a majority of consumers have heard about (around 47% of survey participants), but cost has been ranked as the most important determinant of VR adoption (Baumgartner 2016). Similarly, Bazilian (2017b) also concurred in another survey of 1,000 people between 18 and 64 years old that 37% of the participants decided against buying VR devices after realizing its high cost, and 64% of them agreed that they would buy VR devices if they were less expensive. Thanks to the popularity of smartphones adopted by 68% of the US adults (lessonly.com 2016), this challenge may be resolved sooner.

Secondly, other VR researchers have also observed other important determinants including heightened consumer expectations, availability of VR headsets, new ways of thinking in designing more interactive contents, etc. (Klie 2016). Thirdly, a country's telecommunications infrastructure will also affect if the immersive potential of VR technologies can be fully realized without data transmission delays. Consumers of VR technologies will continue to expect higher frame rates and image quality. As a result, data demand of VR devices are expected to exceed those of 4 K. According to Juniper Research, data consumption is predicted to grow from 2,800 PB in 2017 to over 21,000 PB in 2021 (Laposky 2017). Lastly, the future development of VR technologies also rely on how VR integrates with other popular platforms such as Facebook or WeChat, both of which are currently developing their own VR platforms (Johnson 2017d; Jorner 2017; Laposky 2017).

Augmented Reality (AR)

Similar to VR, augmented reality (AR) also allows users to interact with simulated digital graphics, imagery, and objects that combine both computer-generated virtual and real-world data to make real-time interactions possible, with the illusion of co-existing in the same space (Rese et al. 2017; Van Krevelen and Poelman 2010; Williams 2009). Researchers have claimed that AR is an important branch of VR because both integrate virtual digital information into a 3D real environment in real time (Chen et al. 2016). Therefore, the definitions of AR center on its virtuality, enhanced telepresence and flow experience, and a sense of immersion. For example, Carmigniani and Furth (2011) defined AR as "a real time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it" (p. 342).

Figure 1 best captures how realities are created in the virtual world and where augmented reality stands in this popular Reality-Virtuality



Integrating Virtual Reality and Augmented Reality into Advertising Campaigns: History, Technology, and Future Trends, Fig. 1 A continuum of realities in the virtual world. (Adapted with automatic permission from Kim et al. 2016, p. 162)

(RV) continuum (Milgram et al. 1994). As seen in Fig. 1 (adapted from Kim et al. 2016, p. 162), mixed reality (MR), or Hybrid Reality, is often used as a stand-along application or can be used as an umbrella term that encompasses variations, yet captures "the core efficiencies" of both AR and VR technologies and applications (Milgram et al. 1994; Reality Technologies n.d.; Pando 2017). MR include augmented reality, augmented virtuality, and other mixed reality applications (Reality Technologies n.d.). The concept of mixed reality refers to an application by which real and virtual world objects and people are integrated with the virtual environment where digitally generated and physical objects are juxtaposed to co-exist and to allow users to interact in real time (Milgram et al. 1994; Milgram and Kishino 1994). MR is therefore different from AR because MR analyzes users' surrounding environment before projecting computer-generated contents and synthetic objects that users are able to interact with virtually (Pando 2017). In spite of the conceptual differences, we will use AR and MR interchangeably, following the current practices in the advertising and marketing industry.

As an interactive and immersive media platform, AR offers a great potential to complement what traditional advertising platforms are not able to offer through its innovative ways to interact with commercially relevant advertising contents (Javornik 2016). Unlike these media, AR is characterized with its "interactivity, virtuality (presence of elements of virtual reality), geolocation feature/location specificity, mobility (in terms of portability and wearability) and synchronization of virtual and physical/real (augmentation)" (Javornik 2016, p. 253). These characteristics have made AR a promising platform for many advertisers.

As early as 2010, HarperCollins Publishers has experimented with AR to promote Irish author, Cecelia Athern's book, *The Book of Tomorrow*, in its campaign (everydayismagical.com) (Shields 2010). With the popularity of social media platforms, the agency Stickee also employed Facebook in this multiplatform campaign (Shields 2010). Similarly, Ford's UK campaign (https://www.youtube.com/watch?v=bl8T9oYO5vY) targeted young demographics to encourage their purchase of Ka car model. The technology allows mobile phone users to view images superimposed virtually onto another pictures in a video kiosk (Clifford-Marsh 2009). Advertisers often integrated AR with other integrated marketing communications (IMC) platforms. In its 2017 AR campaign (http://www.benjerry.com/flavors/special-stash), Ben & Jerry worked the advertising agency, 360i, through Facebook's latest augmented reality platform to promote its newly launched marshmallow-flavored ice cream (Johnson 2017d; Loop 2017). This AR campaign also integrated a digital game platform to allow players to use a smartphone's rear-facing camera by allowing them to catch marshmallows falling from the sky. If consumers missed more than five marshmallows, the AR game ended (Johnson 2017d). The ice cream cones at the bottom of the campaign site tracked how many marshmallows have been missed (Johnson 2017d; Loop 2017).

Scholz and Smith (2016) proposed the "layer/world metaphor" (p. 149) to describe the applications of AR in advertising. Advertisers developed digital information layers made up of

pictures, texts, and videos that later overlay with physical objects (e.g., advertisements, landscapes, product packages, street scenes) in the real world (Scholz and Smith 2016). Through digital screens or holograms on digital out-of-home billboards, smartphones, or other video installations, uses are able to experience their virtual presence and "hybridized realities" (Scholz and Smith 2016, pp. 149–150) that generate an illusion that they interact seamlessly and in real time with the computer-generated objects.

In the following 2014 Pepsi Max Unbelievable AR campaign in London (https://www.youtube.com/watch?v=Go9rf9GmYpM), a bus stop was rigged with an digital display capable of producing AR experience to daily commuters. The 6-sheet digital screen displayed computer-generated UFOs, giant hostile robot, and escaped wild tiger images that overlay with live feed of the street (Dyakovskaya 2017). This campaign generated very positive results with 30% sale volume increase, 120,000 mentions, likes, and shares in major social media channels, and 87% earned view rate (Dyakovskaya 2017). The campaign has demonstrated how a UFO attack scenario was overlaid with the street scenes in London (Dyakovskaya 2017). The potential of AR-enabled billboard can be maximized when interactivity is embedded in the campaign when consumers are able to participate in the interactions with AR contents (Szymczyk 2009). Refer to the campaign video site (https://www.youtube.com/watch?v=Go9rf9GmYpM) to experience the role of AR in enhancing consumer engagement.

To conclude this section, *Fortune* magazine predicts that AR will generate $120 billion in revenue by 2020 (Gaudiosi 2015). Gartner (2010) also predicted that AR could be considered as one of the promising top ten technologies in the information-communication technologies (ICT) sector (cited in Kim et al. 2016). At the 2015 Consumer Electronics Show, AR has the potential to "disrupt anything with a screen" (cited in Scholz and Smith 2016, p. 150). The advent of mobile AR content is likely to create the greatest influence on AR applications in the next 5–10 years (Heine 2017; Szymczyk 2009). AR users will be able to personalize their own immersive mobile AR experiences in advertising, entertainment, gaming, retailing, sports, contexts to complete their consumer decision-making journeys (Heine 2017; Rese et al. 2017; Shapiro 2017).

Table 1 below offers a good summary of major advantages of AR and VR as two emerging interactive technologies. These media characteristics offer potentially promising applications for the advertising professionals. For example, interactivity will allow advertisers to develop fully interactive digital ads that allow users to interact and modify ad contents. The hypertextuality feature will enable consumers to access product information embedded in the digital ad and to connect to e-commerce and mobile commerce site to

Integrating Virtual Reality and Augmented Reality into Advertising Campaigns: History, Technology, and Future Trends, Table 1 Technical characteristics of AR and VR technologies

Media characteristics of interactive technologies	Definition
Interactivity	Machine and personal interactivity, feature-based or perceived, composed of control, responsiveness and two-way communication
Hypertextuality	Potentially high number of linked sources
Modality	Diversity of content representation
Connectivity	Technological capability of expanding and sustaining a model of network, where many users can be connected among themselves
Location-Specificity	Specificity with which a technology and its user can be targeted based on the precise geolocation
Mobility	Portability and wearability that allow a mobile use
Virtuality	Combination of virtual elements that causes immersion in an environment constructed with computer graphics and digital video

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purchase advertised products. In addition, the multimodality of both AR and VR technologies has blurred the traditional boundaries of print, electronic, out-of-home media, and emerging media. As a result, traditional print ads are able to offer videos through AR, VR, or holograms, such as Porsche's holographic magazine ad (2016) (https://www.youtube.com/watch?v=XThnCB3s8y0). Connectivity has led to the creation of social media advertising and electronic word of mouth to facilitate the marketing communication processes. Both location-specificity and mobility characteristics allow advertisers to send location-sensitive mobile advertising to consumers' mobile devices and create a pervasive mobile environment. Finally, virtuality of the VR and AR platforms has generated a potential to integrate with other media platforms to create fully immersive advertising experiences.

We used the following VR and AR campaigns to demonstrate the benefits of integrating these two emerging technologies into advertising campaigns to generate positive results.

Integrating AR/VR into Advertising Campaigns

- Campaign Case #1: KFC's "The Hard Way" Virtual Training Escape Room VR Campaign (2017) (https://www.youtube.com/watch?v=GAlD0h9vCEc) (https://www.youtube.com/watch?v=JX5RmKcO_j8)
- Kentucky Fried Chicken (KFC) launched its 25-min VR video game campaign, "The Hard Way," that required users to learn how to fry chicken thighs and wings before they could escape from the virtual Colonel Sanders' secret lodge (KFC Corporation 2017; Swant 2017b). This VR campaign was developed by Wieden + Kennedy's emerging technologies branch, W + K Lodge (Swant 2017b). Though not intended for the public, the campaign was designed to train KFC's new "screen-obsessed" Generation Millennial cooks to have a better understanding of the brand's personality, according to Bob Das, KFC's head check in the USA (Jardine 2017; Swant 2017b). KFC has been proud of its products, claiming "It's made in the hard way" (KFC, https://www.kfc.com/about/how-kfc-makes-chicken). Cook trainees were challenged to interact with the computer-generated objects through an Oculus Rift headset and controller and learned the laborious five-step processes of inspecting, rinsing, breading, racking, and pressure-frying KFC's chicken products before placing these virtual objects in Colonel Sanders' mouth to complete the training (Jardine 2017; Swant 2017b). KFC has planned to use more VR e-learning and training contents to help train its cooks in its multistep and rigorous Chicken Mastery Certification program (KFC Corporation 2017). VR technologies in this campaign have allowed KFC to communicate its corporate mission statement with a fun and hand-on experience. As seen in KFC's press release (2017), "What excites us is experimenting with new tools and mediums to tell stories. VR became an obvious choice to create an immersive experience that teaches trainees how to make KFC's Original Recipe. The escape room concept builds on the pure training and utility of the experience into something that's also entertaining and connected to KFC's iconic founder." Campaign Case #2: NHS Blood and Transplant AR Campaign in UK (2016) (https://www.youtube.com/watch?v=-zNWP4lzrJQ)

This AR campaign was launched in Birmingham and London though its interactive out-of-home digital billboard to change people's stigma about blood donation (Marketing Week 2016). The campaign was created by agency, 23red that prides itself to "change behavior for the better" (Marketing Week 2016). This AR campaign was an excellent demonstration of how an AR app could make the best use of its interactive and multimodal capabilities to create "experiential activities" to increase the awareness of and actual behaviors of blood donations (Benjamin 2016).

The interactive digital billboard showing a sick patient includes a strong message, "I need your blood donation. Can you help? Show your

support by filing a virtual bag." Spectators were given a sticker that could be detected by visual recognition on their smartphone (Benjamin 2016). Afterwards, the AR app allowed them to donate virtually their blood that will ultimately fill out an empty blood bag. Refer to the campaign video link (https://www.youtube.com/watch?v=-zNWP4lzrJQ) that demonstrates the integration of mobile app with AR technologies in this campaign.

As shown in the campaign video (https://www.youtube.com/watch?v=-zNWP4lzrJQ), the pale-looking patient's complexion changed when the blood bag was filled to transfuse the blood, replicating the actual process of blood donation. The digital billboard showed "It is helping already. Just an hour of your time can save or improve three lives." At the end of the virtual blood transfusion, the real patient thanked the donors and demonstrated "the power of a blood donation" (Marketing Week 2016, p. 6). Volunteers were also present on-site to hand out pamphlets about blood donations while a blood donation truck was parked nearby. In addition to its AR platform, the NHS Blood and Transparent campaign also integrated sponsored posts on major social media and organic social activity (Benjamin 2016). The campaign generated positive results with 583 new donor sign-ups across the 5th day and 77,000 viewing of the support videos. The success of this campaign lied on its abilities to make the most of AR's technical advantages to allow users to fully interact with AR contents and subsequently generate the highest level of user-campaign/brand engagement (Scholz and Smith 2016).

Conclusion

The integration of AR and VR technologies into advertising has opened up many opportunities for advertisers and marketers (Javornik 2016). There is no available academic research on which product, service, and company are most suitable to apply AR, VR, or MR technologies in their campaigns. However, quick keyword searches on the industry trade publications (AdWeek or AdAge) found that these emerging technologies have been applied to a variety of brands, ranging from Elle Magazine (O'Shea 2016), social media giant, Twitter (Cohen 2016), Disney's film promotion (Shaul 2014), Gatorade (Schultz 2015), etc.

As demonstrated in the above AR and VR campaigns, consumers are now able to interact and engage with advertisers' messages (Giardina 2017; Martin 2017), to avoid future ad blocking (Martin 2017), to build better brand awareness (Martin 2017), to connect consumers to the product through a self-referencing effect (Baek et al. 2015), to make people better attached to a brand, and to measure campaign effectiveness (Baumgartner 2016). As claimed by many marketing researchers, enhanced consumer engagement is likely to build long-term customer relationship and brand loyalty and has become a strategic competitive advantage (Monllos 2017; Scholz and Smith 2016).

A sense of immersion in the advertising communication process has been found to create consumer engagement and better advertising effectiveness (Martin 2017). Vibrant's test campaigns used VR and 360° video to compare those using traditional 2D video and found better effects were generated in terms of interaction rates (600%), content recall (700%), brand recall (2,700%), and product intent (200%) (Martin 2017). VR ads delivered through consumers' mobile devices continue to generate more positive effects in terms of interaction rates: 85% of VR/360° video versus 2.5% of mobile devices (Martin 2017).

According to a survey of agency clients by *Media Planners and Buyers Insperience*, it was reported that 67% of media buyers and planners were interested in integrating AR and VR into their digital marketing campaigns. Twenty-nine percent of them in the survey had purchased AR or VR ads for their clients (Martin 2017). In general, VR (67%) was favored over AR (17%) in their media buy (Martin 2017). In addition to their appeal to advertisers, marketing practitioners have echoed the same insights from the academic researchers. Felix Lajeunesse, Co-Director of Felix & Paul Studios, concurred with the importance of these technologies by saying, "We

wanted to create the feeling that you are experiencing this environment in a very personal way – feeling the emotion and connection between them and the environment" (cited in Giardina 2017, p. 70).

Despite the hype, the durability of these technologies remains to be a concern since their early introduction (Williams 2009). Information-intensive technologies such as AR and VR will require fast streaming speeds to transmit data to consumers' devices (Laposky 2017). Therefore, whether AR and VR advertising campaigns can be globalized to other countries with less-developed telecommunications infrastructure remains to be an issue. Advertising and marketing research is scarce except for a few empirical or theoretical studies (Baek et al. 2015; Hopp and Gangadharbatla 2016; Javornik 2016; O'Mahony 2015) examining factors to develop more effective AR/VR campaigns. Programmatic research should be conducted to understand better consumer-, system-, message-, and product-related factors to better integrate these technologies into future advertising campaigns. Furthermore, ethical challenges also emerge with "immersive storytelling" about a brand and manipulated realities by advertisers who use AR and VR (Webb 2016).

Cross-References

- ▶ Accessibility of Virtual Reality for Persons with Disabilities
- ▶ Augmented Reality Entertainment: Taking Gaming Out of the Box
- ▶ Augmented Reality for Maintenance
- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Interactive Augmented Reality to Support Education

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Intellectual Disability

► Computer Games for People with Disability

Intellectual Property

► Computer Games and the Evolution of Digital Rights

Intellectual Property Rights

► Computer Games and the Evolution of Digital Rights

Intelligent Argent

► Emotion-Based 3D CG Character Behaviors

Intelligent Dynamic System

► 2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making

Intelligent Transportation Systems

► Potential of Augmented Reality for Intelligent Transportation Systems
► User Interface (UI) in Semiautonomous Vehicles

Intelligent User Interface

► Emotion-Based 3D CG Character Behaviors

Intelligent Virtual Environment

► Emotion-Based 3D CG Character Behaviors

Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality

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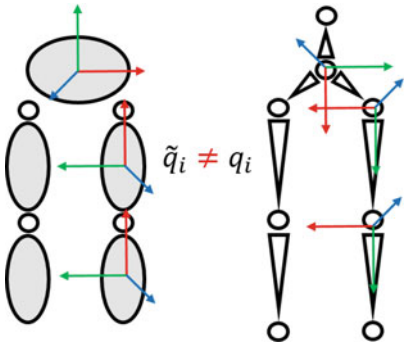
Synonyms

Character - Avatar; SIMBICON - Simple Biped Control; Embodied Agent - Autonomous Digital Character; Augmented Reality; Virtual Reality

Definitions

Simulated characters offer rich and realistic interactions with users and dynamic environments. They can be thought of as compliant robots in the real world. Hence, for every unique push or perturbation, the character responds equally in a unique and realistic fashion. As the result, the immersion for the user is greatly increased and all the more powerful. This article provides insights on how to make compelling interactions with a a self-balancing bipedal character in Virtual and Augmented Reality settings. It also describes a general method to interface a simulated character with a traditional skeleton, used in modern game engines such as Unity and Unreal Engine – thereby making simulated characters more accessible.



Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality, Fig. 1 Because kinematic skeletons (right) are designed by different digital artists, the relative rotations q_i in the parent frames are not consistent across characters and typically do not correspond to the same relative rotations $\tilde{q}_i$ in an articulated rigid body system (left). In consequence, relative rotations from a simulated character cannot be applied directly to those of a kinematic skeleton, typically used in game engines

Introduction

High-level game engines such as *Unity* and *Unreal Engine* make easily accessible state-of-the-art graphics and rendering. However, their character animation systems are based on the *state machine/blend tree* kinematic controller, which blends between motion clips. This quickly leads to repetitive animations and reactions, and increasing the realism requires exponential amounts of motion clips. In the past decades, progress has been made in the area of simulated characters, which allow to constantly generate realistic and novel motions on the fly. Because the representation of an *articulated rigid body system* (ARBS) is different from a *kinematic skeleton* (KS) used in games, it is not possible to directly use simulated characters to drive the character's motion in the game engine. Kinematic skeletons are used to deform the character's mesh through linear blend skinning (LBS). Typically it is possible to set relative rotations to the skeleton joints (but not the world transforms or access the full LBS equations). The problem is that the articulated rigid body systems and the kinematic skeletons are often different, and hold different local coordinate systems, as shown in Fig. 1. Hence it is required to transfer the joint transformations from the ARBS into relative transforms, expressed in the coordinate system of the KS. This can be formulated as an optimization problem, where a set of features are to match in the world frame, and the free variables are the joint rotations. However, this requires iterative numerical optimization, which is computationally costly. This article describes a fast analytical algorithm that solves this problem sequentially, joint-by-joint. With this algorithm, it is possible to use an external simulation and control library directly in *Unity* and have a casual user experiment with a standard bipedal controller, in particular a type of controller called SIMBICON (Simple Biped Control, Coros et al. 2010) which combines PD tracking of locomotion poses with virtual forces for balancing the center-of-mass. This article describes two different interactions with the environment usable both in AR and VR: perturbations and terrain adaptation. This allows to have an AR character walk over real world terrain or have objects thrown at the character while having him react in a unique way each time. Making these interactions compelling is actually not trivial, and this article provides insights on overcoming these hindrances.

Related Work

The standard animation system used in game engines today is the *state machine/blend tree* model which transitions between motion clips (i.e., states) similar to motion graphs (Kovar et al. 2002) and blends between *well-aligned* motion clips (i.e., blend trees), such as in *Verbs and Adverbs* (Rose et al. 1998). Putting this type of kinematic controller together requires extensive manual labor in order to loop motion clips and align them properly. Also, for every new motion and interaction, a new motion clip must be created and inserted into the graph structure, resulting in exponential growth of the graph. One way to reduce the amount of hand-crafted clips is to retarget the clips using layered inverse kinematics (IK), as to adjust the position of end-effectors to new grabbing positions, or contact points (e.g., NaturalMotion, Ikenema, FinalIK, and more).

While this approach is popular, it lacks fast response to user controls and requires a large manual effort to build and maintain. One idea to increase the responsiveness is to stich small motion clips together online using some estimate of a state-dependent cumulative reward (Arikan et al. 2005; Lee et al. 2010; Levine et al. 2012). This approach has been used in practice in the game *For Honour* (Clavet 2016), along a large data-set of human motion constructed with motion capture. Recently, Holden et al. have learned the control parameters directly with a deep neural network (Holden et al. 2017). While motion capture is still mostly available for human subjects and requires considerable time to capture and clean the motion clips, this approach is gaining traction in games to increase the realism of character motions. Unfortunately, it cannot be used directly onto a different character if the coordinate systems of the joints are different.

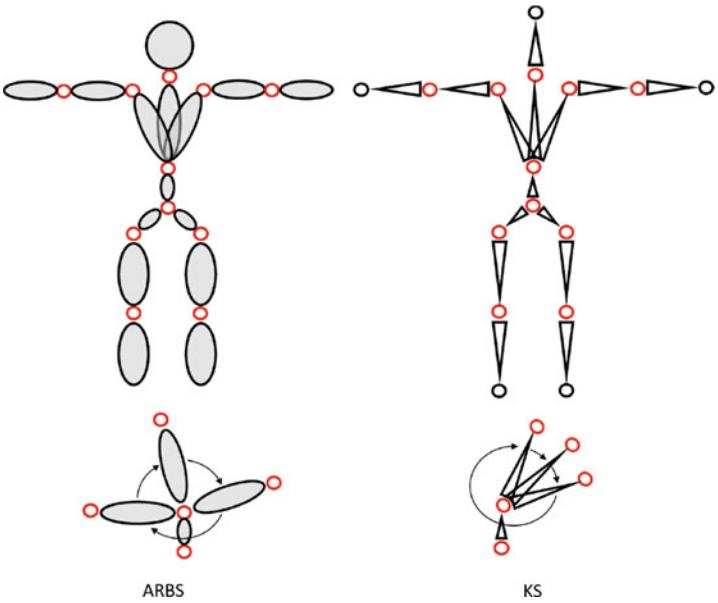
Motion transfer. Transferring motion from one character or source of motion to another character has been used and studied in many applications. This is often formulated as an optimization problem where a set of features (position, orientation) on the target character are to match the source character's features (Chai and Hodgins 2005; Choi and Ko 1999; Gleicher 1997; Seol et al. 2013).

Gleicher et al. applied this to whole motions in order to transfer motions between characters of different proportions (Gleicher 1997). Solving for individual poses (one at a time, together with smoothness) is less prone to local minima. Also many applications do not have access to whole motion, as is the case with performance animation (Chai and Hodgins 2005; Seol et al. 2013). The methods above use iterative numerical algorithms to solve the optimization problem, while in contrast, this article describes an analytical solution – assuming the same topology and access to the full source motion.

Others have used corresponding motion clips to compute an explicit transfer function from pose-to-pose (Dontcheva et al. 2003; Yamane et al. 2010; Rhodin et al. 2014), typically through a regression (Dontcheva et al. 2003) or through a shared sub-space (Yamane et al. 2010). However, an explicit transfer function is never completely accurate and leads to drift in visually important features such as foot contacts, hence requiring additional optimization iterations to fix.

Simulated characters. Another vision to increase the realism of characters is to embed them in a simulation, as if in the real world. This is a long and lasting effort in computer animation, as seminal works started with manually crafted controllers for human athletics in 1995 (Hodgins et al. 1995). Since then, controllers have been specifically engineered for locomotion using simplified balance models such as the inverted pendulum (Yin et al. 2007; Coros et al. 2010; Lee et al. 2010; Coros et al. 2011). While these controllers are very robust, they can only track locomotion and do not extend easily to other types of motions.

Many have tried to use inverse dynamics to track motion capture, assuming knowledge of the full equations of motion. Given the dynamics of the system in generalized coordinates, it is possible to estimate the torques required to match acceleration-based targets (e.g., mocap



Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality, Fig. 2 Using the naive joint-to-joint structure leads to more freedom of motion for the simulated ARBS compared to the KS. In consequence, some poses in the simulation cannot be reached by the kinematic skeleton in the game, as shown by the example with the upper body at the bottom of this figure

targets) by solving a quadratic program constrained to match dynamics and ground reaction forces (Abe et al. 2007; Da Silva et al. 2008; Macchietto et al. 2009; Mordatch et al. 2010; de Lasa et al. 2010; Levine et al. 2012; Rabbani et al. 2014). In practice, this controller requires parameter fine-tuning and feasible objectives. Recently, there has been a renewed interest in using reinforcement learning to learn robust feedback policies for a great class of motions (Tan et al. 2014; Peng et al. 2016; Peng et al. 2017) or guided learning by alternating between open-loop control optimization and feedback fitting through regression (Liu et al. 2016).

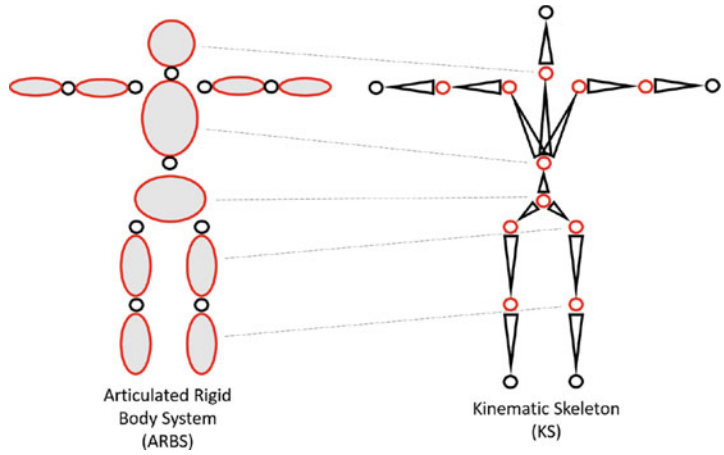
While physics-based controllers are an exciting approach to character animation, they remain out of reach to casual users and interaction designers that operate in high-level game engines. By providing a familiar interface – the kinematic skeleton – around these controllers, the possibility to use them in many applications is greatly increased.

Fast Pose Transfer

This section describes how to transfer the motion from an *articulated rigid system* (ARBS) to a *kinematic skeleton* (KS) typically used in game engines and motion authoring software such as Maya. It is first required to define which type of ARBS our transfer algorithm supports. The naive approach to building an ARBS from a KS is to associate joints together. However, this leads to an excess *freedom* problem. In other words, the ARBS can reach configurations the KS cannot, thus preventing from directly transferring the transforms from the former to the later, as shown in Fig. 2. The solution to this problem is to associate the KS joints to a rigid body, as shown below in Fig. 3.

With a suitable ARBS, it is possible to tackle the problem of transferring the motion from the ARBS to the KS. Since animation systems in game engines typically allow to only set relative rotations to the joints, it is required to recover relative transforms. Note this cannot be simply computed directly from one and applied to the other, as the parent coordinate systems differ in each model, as shown in Fig. 1. The main insight behind this solution is to compute the absolute world transform, relative to the initial transform and transfer this quantity to the KS, and then recover the local relative joint transforms.

More formally, the root position for the ARBS is denoted as $\widetilde{u}$, the local rotation as $\widetilde{q}$, and the



Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality, Fig. 3 Our solution to avoiding excess freedom of the ARBS: the joints on the kinematic skeleton (KS) correspond to rigid bodies on the ARBS – the ARBS should be the dual of the KS

world rotation as $\widetilde{Q}$. Similarly for the KS, the root position is denoted as u, the local and world rotation as q and Q, respectively. Time is denoted $*(t)$ and the index i is a notation abuse to traverse the joints in a hierarchy with $i-1$ being the parent of i.

At the beginning, the initial root offset between the ARBS and KS is stored, as well as all the world orientations of the ARBS bodies and KS joints:

$$\text{Root off set}: \quad \Delta x(0) = \widetilde{u}(0) - u(0) \tag{1}$$

$$\text{World orientations}: \quad Q_i(0), \widetilde{Q}_i(0) \tag{2}$$

Then the process starts from the root joint of the KS, and sequentially traverses down each chain of joints/bodies to transfer the rotations from the ARBS bodies in world, to relative joint rotations in the KS, as follows:

First, we compute the ARBS rotation relative to its initial pose in world frame:

$$\widehat{Q}_i(t) = \widetilde{Q}_i^{-1}(0)\widetilde{Q}_i(t)$$

Then we compose the ARBS rotation with the initial KS world rotation to obtain the current KS world transform:

$$Q_i(t) = \widehat{Q}_i(t)Q_i(0)$$

Finally, we recover the KS transform relative to the parent:

$$q_i(t) = Q_{i-1}^{-1}(t)Q_i(t)$$

where Q_{i-1} represents the orientation of the parent joint. Note the root is a special case:

$$Q_0(t) = \widehat{Q}_0(t) \tag{3}$$

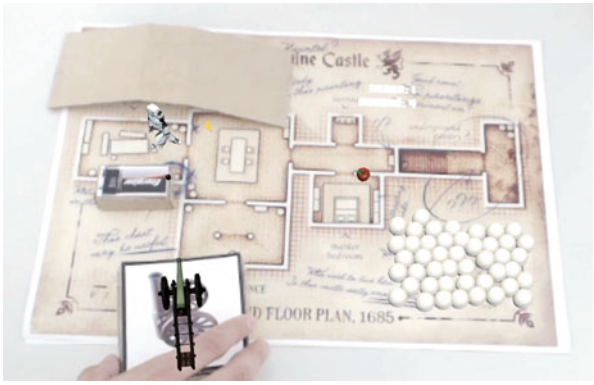
$$u(t) = \widetilde{u}(t) - \Delta x(0) \tag{4}$$

This transfer is applied at each frame of the animation. The next section describes experiments with transferring the motion from a SIMBICON-type of simulated character in VR.

AR VR Interactions

Typically simulation and control engines are implemented in fast native code (C++). However, high-level game engines use high-level managed or scripting languages such as C# or Lua. The experiments described in this section were done with the *Unity* game engine, which offers the possibility to load native libraries as plugins.

Objects in the game engine that need to interact with the character require rigid body properties

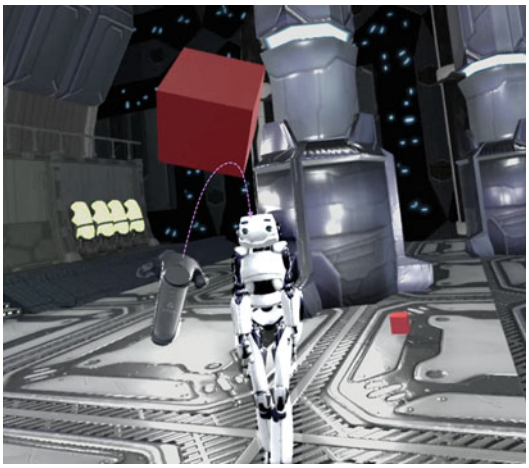


Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality, Fig. 4 We can augment a real world environment with the virtual simulated character. The simulated character can interact with real and virtual objects in the scene. Here we see virtual cannon balls shot at the character

and colliders to be given to the simulated. This works as follows: the user can tag an object as a simulated object, whose geometry is used to initialize the mass, moment of inertia, and collider shape. Given a character mesh and a kinematic skeleton, an ARBS is created and then fixed. Applications can still use different character meshes with the same bone topology, ideally with the same proportions, but note that proportions have no effect on the simulation. For example, if the legs are longer, the feet would simply penetrate the ground visually, but not affect the behavior of the simulator (Fig. 4).

Designers conducted two types of interactions with a SIMBICON character in AR and VR. The simulated character reacts to perturbations in the environment. However, the controller is designed around a simplified rigid body system with simple collision primitives (cubes and ellipses), resulting in repetitive collisions and reactions. Described next is a solution to generate more variations and increase the immersion.

Secondly, the controller seeks to maintain balance at every step. One benefit of this is the ability to cope with various terrains. It is possible to detect objects in the environment and have the character walk over different terrain profiles. Also, the designers created a new type of game where the user tries to steer the character towards a goal, by manipulating the ground underneath the character. But first, before delving into the meat of things, the SIMBICON controller is briefly described.



Brief SIMBICON Description

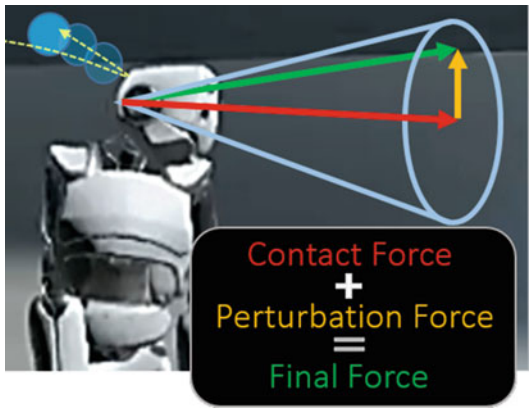
This controller relies on a simplified analytic balance model to perform locomotion. A few interpolated keyframes define the target poses for a walk cycle. To maintain balance, the foot placement position is computed with an inverted pendulum model, and the corresponding leg shape in the target pose is determined through an analytical inverse kinematics (IK). The torques driving the simulation are computed through PD-control (given the target pose), together with virtual forces – using the Jacobian transpose – to better control the velocity and root orientation of the character.

Perturbations

Users experimented with throwing objects at the simulated character in both AR and VR. While

Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality, Fig. 5 Character can walk over real world terrain, as show on the left here with cardboard in the shape of a bridge. On the right, we see a balancing game in VR where the user controls a ground with two vive controllers

seeing the character's ability to self-balance is fun, the reactions to the perturbations became *visually* repetitive even though they are being generated online through the simulator. It could be due to the simple collision primitives used to model the character's mechanics. To have more variations in the reactions, without increasing the complexity of the model, it is possible to detect the collisions with objects, recover the contact force, and slightly deviate its direction within a cone radius.



Note that several alternatives were tried, such as adding multiple collision detection primitives to have more diversity in the contact configurations, as well as simply adding random forces at contact events. In the first case, more primitives did not improve much the drama and caused the simulator to slow down. The second idea was hard to fine tune properly and led to this solution: generate a cone based on the collision point and direction, as well as magnitude, and sample a random vector inside this cone, which would then be applied as the new force. This resulted in more variate behaviors.

Balancing the Character

A self-balancing mechanism can be quite an amusing feature to watch and interact with. A small game was devised where the user controls the plane below the character. The character moves towards the steepest point on the plane. This allows the user to guide the character towards objectives (milestones) by tilting the plane. The player has to carefully tilt the plane such that the inclination does not exceed the characters capabilities, which would make the character fall. Figure 5 shows a screenshot of the balance game.

Conclusion

This entry described a solution to using advanced simulated characters in high-level game engines such as Unity. This allows casual users to create interactive AR and VR games centered around realistic reactions to perturbations and self-balancing, which would be laborious to setup with the mainstream *blend tree* type of controller currently offered in game engines.

Cross-References

▶ Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science

- ▶ Augmented Learning Experience for School Education
- ▶ Augmented Reality Entertainment: Taking Gaming Out of the Box
- ▶ Augmented Reality for Maintenance
- ▶ Character Animation Scripting Environment
- ▶ Crowd Simulation
- ▶ Emotion-Based 3D CG Character Behaviors
- ▶ Interactive Augmented Reality to Support Education
- ▶ Sketch-Based Posing for 3D Animation

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I

Interaction

▶ Virtual Reality: A Model for Understanding Immersive Computing

Interaction Techniques

▶ Locomotion in Virtual Reality Video Games

Interaction with Mobile Augmented Reality Environments

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Synonyms

Augmented reality; Mediated reality; Mixed reality; MR

Definition

Augmented reality is a technology that combines virtual and real worlds in real time to help users complete their work or to provide users new experiences.

Introduction

Augmented reality technologies have been widely applied to military, industry, medical, and entertainment areas. The rapid spread of smart mobile devices such as smart phones and smart pads has made it possible to experience AR on smart mobile devices. Various AR applications including games have been developed on mobile devices using sensors such as a camera, a GPS, and an inertial sensor, yet most of them only provide simple interaction for the users. Better 3D interaction techniques are needed to extend the usability of mobile AR applications.

In this article, we will introduce a 3D interaction technique suitable for mobile AR applications developed at the mixed reality and interaction (MRI) laboratory recently. The 3D interaction technique had been developed concentrating on object manipulations.

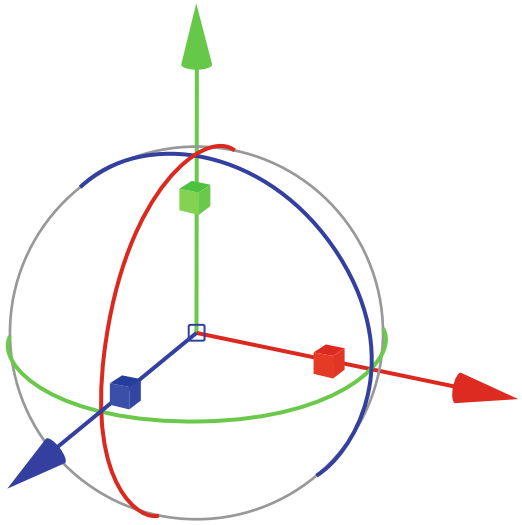
State-of-the-Art Work

3D Interaction in AR Environments

There is little research on interactions of mobile AR systems with a small display. Anders Henrysson et al. developed two interaction techniques. They used an AR-enabled mobile phone as a tangible interaction device. In Henrysson et al. (2005), the mobile phone itself was manipulated to control an object after selecting it in a 3D AR environment. In Henrysson and Billinghurst (2007), they extended the interaction technique developed in 2005 for mesh editing. They selected multiple points on a mesh and the selected vertices are locked relative to the camera. Now a user could move the mobile phone to translate and rotate the selected object or points after they chose the motion type.

Touch-Based Interaction for 3D Manipulation

Touch-based interaction techniques have been applied to manipulate 3D objections in a few virtual reality systems. These interaction techniques are categorized into two types: constrained and unconstrained. Constrained interaction techniques are able to manipulate 3D objects precisely. The constrained interaction techniques separate the control of degree of freedom (DOF) to restrict the movements of 3D objects. A widget, which acts as a visual guidance for the predefined constraints, is typically used to restrict the movements of 3D objects in the constrained interaction techniques. Figure 1 shows a standard 3D transformation widget. A user can select one of three arrows in the widget to set a translation direction or one of three circles to set a rotation axis. Any



Interaction with Mobile Augmented Reality Environments, Fig. 1 A standard 3D transformation widget (Cohé et al. 2011)

user's motions are then applied along the selected direction or the selected rotation axis.

A boxlike widget, tBox, was developed in Cohé et al. (2011). The edges and the faces of tBox were used for translation and rotation of the selected object, respectively. Users can select and manipulate edges and faces of tBox easily with a fingertip. Widgets were designed to be more tolerable to imprecise touch inputs even though careful touch positioning was still necessary. Schmidt et al. developed a single touch interaction technique with transient 3D widgets (Schmidt et al. 2008). Stroke-based gestures were used to create translation and rotation widgets. The standard click-and-drag interaction was used for manipulation.

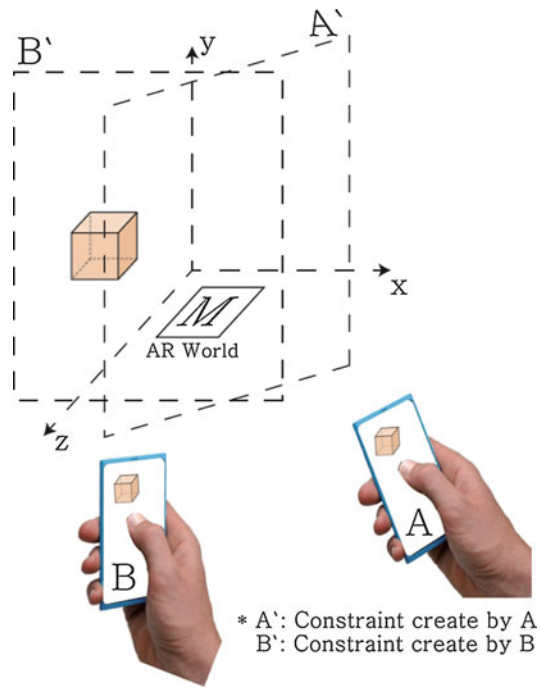
A few constrained interaction techniques have been developed for multi-touch inputs without a widget. Oscar K.C. Au et al. introduced the widgetless constrained multi-touch interaction on a 10.1 inch display (Au et al. 2012). A user selected the constraint without directly touching the constraint mark. The orientation of two touched fingers was compared with the predefined axes to select the constraint. The constraint marks were displayed only as a visual guidance to users. This solved the fat-finger problem causing an error on a device where the screen elements were too small compared to a finger.

Unconstrained interaction techniques do not use a 3D transformation widget that visually guides possible motions of a 3D object. Users can transform an object along an arbitrary direction or axis with the unconstrained interaction techniques. Users can also translate and rotate a 3D object simultaneously with the unconstrained ones so they are typically useful for fast and coarse manipulations.

M. Hancock et al. introduced the Sticky Tools technique in Hancock et al. (2009) to control the full 6DOF of objects. Users select a virtual object by touching it with their two fingers. Users move the two touched fingers and rotate the two touched fingers relative to one another to manipulate the virtual object. While users manipulate the virtual objects, user's two fingers should stay in touch with it. Anthony Martinet et al. developed DS3 (Depth-Separated Screen-Space) interaction techniques to manipulate 3D objects in a multi-touch device (Martinet et al. 2012). They combined constrained and unconstrained approaches and applied different techniques for translation and rotation. The selected object was translated along the axis or the plane defined with one or two fingers. It was rotated freely using the constrain solver, which was introduced by Reisman et al. in Reisman et al. (2009). Translation and rotation were clearly separated by the number of fingers directly in contact with the object. Nicholas Katzakis et al. used a mobile device as the game controller in Katzakis et al. (2011). They developed an interaction technique that could control a 3D cursor on a large display without directly touching the large display. The plane defined by the orientation of a mobile device was casted on the large display. The user could move the cursor on the casted plane using touch inputs on the display of the mobile device.

The last three interaction techniques are good solutions for a virtual environment with a touch-based display, but they cannot be directly applied to mobile AR environments with a small display. The Sticky Tools and DS3 interaction techniques require direct contacts with an object. This requirement is not applicable for a mobile AR

system. Fingers will occupy too much area of the display. The constraint solver could be burdensome for the processor of the mobile device, which has limited processing power. The interaction technique proposed by Oscar K.C. Au et al. could be applied to the device with a small display because they do not require direct contact with the constraint marks. The possible problems with this technique are clutter caused by visual guidance and two required touched fingers. The plane casting interaction developed by Nicholas Katzakis could be adapted to a mobile AR environment since the position and orientation of the mobile device are tracked in real time. This tracked information could be used to constrain the motion of a 3D object in the mobile AR environment. We adapted this plane casting interaction to the proposed interaction techniques.



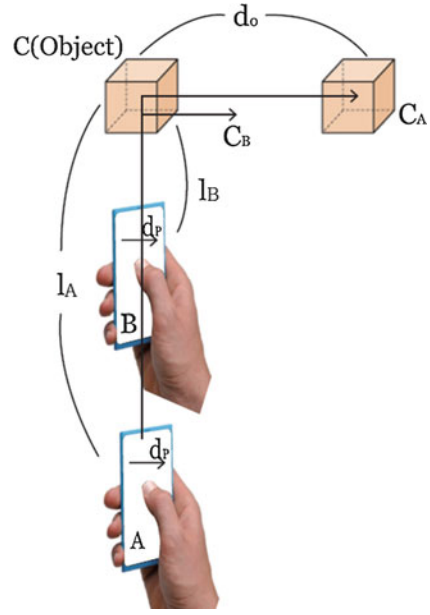
Interaction with Mobile Augmented Reality Environments, Fig. 2 Dynamic constraints

Overview

We developed a new interaction technique for mobile AR systems with following three characteristics: (1) combining constrained and unconstrained interaction techniques, (2) using relations between real objects and a smart mobile device, and (3) combining a way to manipulate real objects and a touch interface of a smart mobile device. The proposed interaction technique aims at providing intuitive and effective interaction when a user manipulates virtual objects in mobile AR world.

3D Interaction in Mobile AR Environments

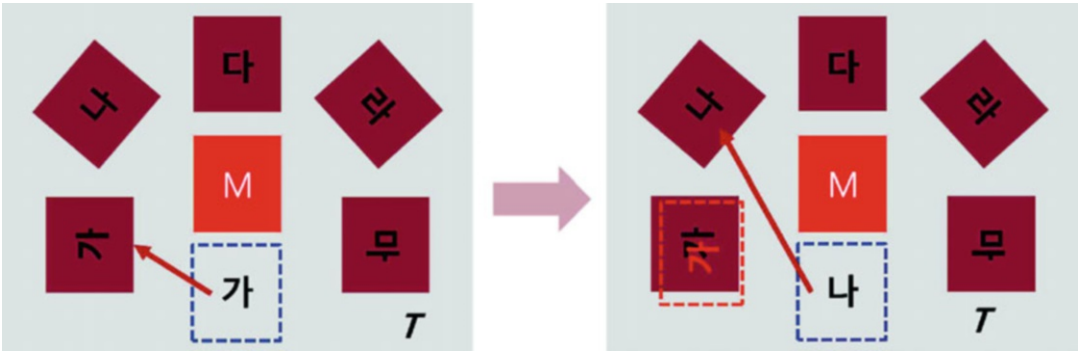
We designed a new interaction technique for mobile AR systems with three characteristics described in the earlier paragraphs. The interaction technique uses the movements of a mobile device to change constraints and a mapping ratio dynamically as shown in Figs. 2 and 3. After moving the mobile device, the plane created by the orientation of the mobile device is projected onto the coordinate of the selected virtual object in an AR world. For example, the mobile devices



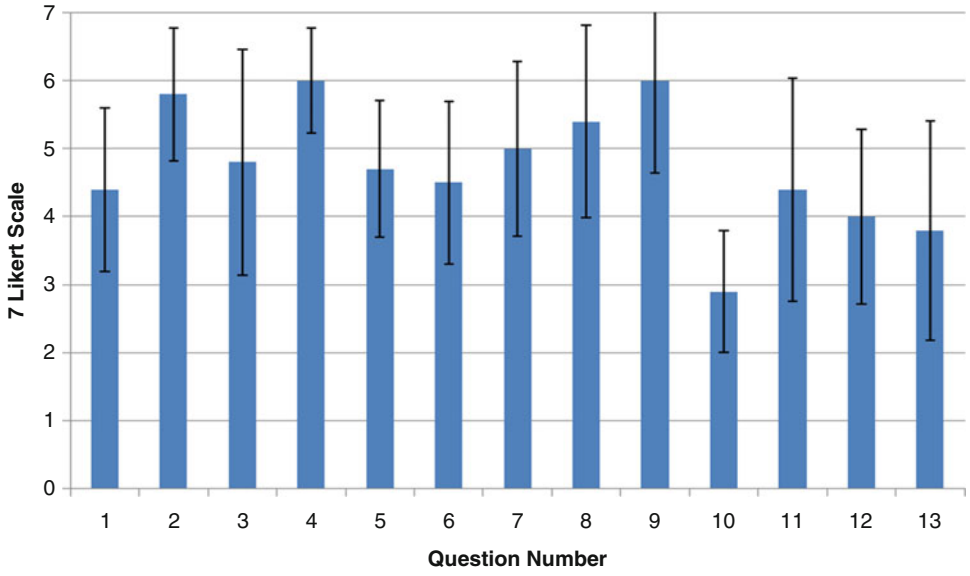
Interaction with Mobile Augmented Reality Environments, Fig. 3 Dynamic mapping distance

A and B in Fig. 2 are projected onto the coordinates of a cube object as plane A' and plane B' passing through the origin of the selected object coordinate, respectively. A user can translate the object along the projected plane, which is the constraint plane, by a simple drag motion shown in Fig. 4. By changing the constraint plane, a user can translate the object to any location with simple drag motions on the display. Figure 5 shows the mapping between the translations on the AR world and motions on the display. The 2D motion E on the display is projected onto the constraint plane D as E'. A user can move the selected object B along the E' direction using the 2D motion E on the display.

The moving distance of the object is dependent on the distance of the mobile device as shown in Fig. 3. When the mobile device is located at location A, the drag motion translates the virtual object C to the location C_A. The same drag motion on the display of the mobile device at B will translate the C to the location C_B. The distance between C and C_A is twice as long as the distance between C and C_B since the distance between C and A is twice as long as the distance between C and B. This mapping is represented in Eq. 1 where α is the



Interaction with Mobile Augmented Reality Environments, Fig. 4 The setting of the usability test



Interaction with Mobile Augmented Reality Environments, Fig. 5 User preference

mapping ratio between d_p, the distance of the drag motion, and d_o, the translated distance of the virtual object C.

$$d_o = d_p \times l \times \alpha \quad (1)$$

The tapping on a mode-changing button is used to change the interaction mode between translation and rotation. In the rotation mode, the axis of the rotation is defined as the axis orthogonal to the direction of the drag motion on the constraint plane created by the orientation of a mobile device. The axis b is orthogonal to the drag motion a. The scaling is done with pinch and spreading motions. The scaling is also constrained by the projection plane defined by the orientation of a mobile device. The ratio of the scaling is determined dynamically based on the distance between the mobile device and the selected object similar to the translation.

Experiments

We designed and performed a user study to evaluate the presented interaction technique. We examined the subjective intuitiveness such as ease of use, ease to learn, naturalness, preference, and fun.

We developed a docking task, manipulated virtual objects (indicated by the dotted lines), and arranged them along the real objects (indicated by the filled rectangular) on table T (Fig. 4). We asked participants to put five virtual characters on the top of the same real characters as shown in Fig. 4. Five virtual characters randomly appeared at the starting location, the lower center of T. To enforce 3D manipulation, the position, the orientation, and the size of each virtual character were randomly assigned. If each virtual object was closely posed with a similar size to the corresponding real object, it was considered as successfully docked and the virtual object disappeared, and the next virtual one appeared at the starting location again (see the right part of Fig. 4). The rectangular with the character M was the location of a pattern used for tracking the camera of a smart phone.

The usability test consisted of two periods: training and final test periods. Participants were trained until their performance improvements were saturated or they felt comfortable with the test. Participants generally took 30–45 min for the training period. The number of trials and the learning time were measured during the training period. The numbers of translation, rotation, and scaling operations and the task completion time were measured for each trial. Before the usability test, we asked participants to fill up the questionnaires to understand participants' backgrounds. The numbers of translation, rotation, and scaling operations and the task completion time were also measured during the final test. After the training and the final test period, participants were asked to fill up the questionnaires shown in Table 1 to measure the preference of interaction techniques and the opinions about interaction techniques.

Ten participants (four males and six females) with normal or corrected vision took part in the experiment. They were volunteers coming for the experiment and we gave them a small gift. All participants owned smart phones and seven

Interaction with Mobile Augmented Reality Environments, Table 1 Questionnaires to measure the participants' preferences of the interaction techniques (7 Likert scale)

No.	Questions
Q1	The interaction technique was easy to use
Q2	The interaction technique was easy to learn
Q3	The interaction technique was natural to use
Q4	The interaction technique was easy to remember
Q5	It was easy to view the pattern required for using the augmented reality system
Q6	The augmented object was lost few times, but they did not cause a big problem to complete the given task
Q7	The interaction technique was generally satisfactory
Q8	The interaction technique was fun
Q9	It was easy to move the augmented object to the target location
Q10	It was easy to rotate the augmented object to the target orientation
Q11	There wasn't a major problem to complete the given task
Q12	The size of the display was suitable for the interaction technique
Q13	It was easy to use one hand for the interaction technique

participants have heard about AR. Three participants have used AR apps before, but they only used them few times. We selected young participants for the experiment since they were generally more familiar with new technologies and more willing to learn new technologies.

Average ratings are summarized in Fig. 5. Overall, the presented interaction technique achieved good ratings in all questions except Q10 and Q13. The interaction technique was considered easy to learn, easy to remember, and fun. Users had difficulty applying rotation motion to the selected object and using the mobile device with one hand.

Conclusion and Discussion

Understanding the characteristics of mobile AR systems can lead to the development of more effective 3D interaction schemes in the mobile AR applications. Important findings from the usability study with the presented interaction technique can be summarized as:

1. The hybrid touch-based interface, combining constrained and unconstrained interaction techniques, is easy to learn and easy to remember for the given task. The participants' familiarities to the touch-based interface could affect the results.
2. Users have to view the given pattern through their cameras for AR applications using computer vision techniques. Participants were not bothered much by this requirement for the presented interface. This is an encouraging result because computer vision techniques are used often to create mobile AR applications. Participants also responded positively to the losses of augmented objects due to tracking failures.
3. Users do not want to move around the AR environment yet. The geometrical relations between augmented virtual objects and real objects are important in an AR environment, so users have to move around the AR environment. In the experiment, participants preferred to rotate the real environment, which is the board that contains all real objects used in the experiment. We would fix all real objects for the next user experiment to understand the behaviors of the participants better in an AR environment.

In addition, our experience suggests that we have to modify the rotation interaction of the presented interaction technique to provide users with better user interactions. Participants had the most difficult time when they had to rotate the augmented objects in the desired direction. Participants also provided useful comments. During the training period, they complained about discomfort in their arms caused by holding the smart phone for a long period of time. This aspect regarding discomfort should also be considered while developing mobile AR applications if they are to be truly user-friendly.

Cross-References

- ▶ Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology
- ▶ Integrating Virtual Reality and Augmented Reality into Advertising Campaigns: History, Technology, and Future Trends

References and Further Reading

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Interactive Art

▶ Biosensing in Interactive Art: A User-Centered Taxonomy

Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld

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Synonyms

Augmented Reality; PUN: Photon Unity Network

Definition

Handheld augmented reality (AR) has been widely used with smart and portable device in the applications such as education, games, visual experience, and information visualization. However, most of the handheld applications do not fully support natural interaction, and the existing 3D pop-up book has used touch-based to interact with 3D content. Therefore, this entry describes a fundamental to design an interactive AR pop-up book with natural gesture interaction using real hand. Subsequently, the real hand gesture tracking in handheld AR is explored to examine how it can track user's hands in real time. Thus, this entry describes about gesture interaction to allow the user to directly interact with the virtual objects. The user feels more realistic to interact with 3D objects using their bare hands on 3D pop-up book.

Introduction

Augmented reality (AR)33 is a technology that allows computer-generated information or digital information including text, video, 2D virtual images, and 3D virtual objects to be overlaid onto the real-world environment in real time (Ismail and Sunar 2013). The main reason people intend to develop AR application is to merge the real world into the virtual world to provide the users with information-enhanced environment (Billinghurst et al. 2008). The connection between these two worlds seems impossible back then, but now it becomes an attraction, and its potential was very overwhelming. Usually, the virtual elements are generated by the computer and made to be overlaid onto the real world, to enhance the user's sensory perception of the augmented world they are seeing or interacting with.

Nowadays, the concept of AR technology is used widely in entertainment, military training, engineering design, robotics, manufacturing, and other industries. AR technologies bring a lot of advantages to perform a task especially once it involves with design and planning. AR has the ability to perform 3D object manipulation and can provide natural user interaction techniques (Ismail and Sunar 2013). All developers take an advantage on AR technologies and believe it could help them to perform real task in virtual way easily besides reducing cost for real task and able to solve many issues which cannot be remedied in the real world.

The level of immersion for both elements of virtual and real objects in AR application refers to the merging of real and virtual worlds to produce AR environments and visualizations where real and digital objects coexist and interact in real time (Azuma et al. 2001). According to Ismail and Sunar 2013, a tracking process is very important in developing AR application and in running it in real time. The main requirements for trackers are high accuracy and little latency at a reasonable cost. The tracking of objects in the scene amounts to calculating the pose between the camera and the objects. Virtual objects can then be projected into the scene using the pose.

Augmented Reality Handheld Interface

There are three main fundamentals that can be found: tracking, display technology, and interaction (Billinghurst et al. 2008). Tracking is one of the fundamental parts in enabling technologies in AR, and it still have many problems that are unsolved (Ismail and Sunar 2013). Interaction technique issues in mobile AR and multimodal AR are becoming more popular. In vision-based interaction, hand and fingertip tracking and hand gesture recognition method are widely used to provide an easy way to interact with virtual object in AR (Chun and Lee 2012). A real-time vision-based approach was introduced to manipulate the overlaid virtual objects dynamically in a marker-less AR system using bare hand with a single camera (Cohen et al. 1989). It is natural that the collision between the human hand and the augmented object can occur during manipulation of the virtual 3D object. In AR, however, the collision happened between a virtual object and a real object; thus, the collision detection approach may be different compared with the ways in the real world. Most AR-handheld applications are not applying a natural interaction, and the user interactions mostly are using touch-based (Kim and Lee 2016). Therefore, this entry describes the interaction in an interactive pop-up book with natural gesture interaction using real hand in handheld interface.

The existing AR book which is generally known as the magic book contains 3D virtual and animated content registered on real book pages, mimicking a traditional "pop-up book" (Markouzis and Fessakis 2015). AR pop-up book is a book that involves the process of overlaying a virtual content onto the pages of a physical pop-up book. The current existing AR book that uses similar metaphor is MagicBook (Billinghurst et al. 2001). MagicBook offers the user the ability to experience the full reality-virtuality continuum. This is because the MagicBook itself is capable of changing the mode between AR and VR. Through AR display, the user is able to see a scene alike, and they could change the view mode to an immersive virtual environment. Another application that adopted the AR book metaphor is AR coloring book (Clark et al. 2011). The AR coloring book aims at augmenting an educational coloring book with user-generated AR virtual content.

Handheld interfaces have four interaction techniques that have been recently explored: touch-based interaction (Kim and Lee 2016), midair gesture-based interaction (Vuibert et al. 2015), device-based interaction (Samini and Palmerius 2016), and direct interaction (Hilliges et al. 2018). The traditional touch-based interaction methods for handheld AR cannot provide intuitive 3D interaction due to a lack of natural gesture input with real-time depth information (as agreed by Bai et al. 2013). Therefore, this entry aims to illustrate the design of natural interaction techniques in 3D spaces by handheld AR devices. Positions and movements of the user's fingertips are corresponding to the manipulations of the virtual objects in the AR scene (as recommended in Bai et al. 2013).

Augmented Reality Pop-Up Book

There are three phases carried out to develop AR pop-up book that are described in the following subsections.

Phase 1: Defining Interactivity and Storytelling for AR Pop-Up Book

The interactivity for an interactive book happens when it contains story and activities which required the user to perform and interact. The real pop-up book does offer a lot of advantages,

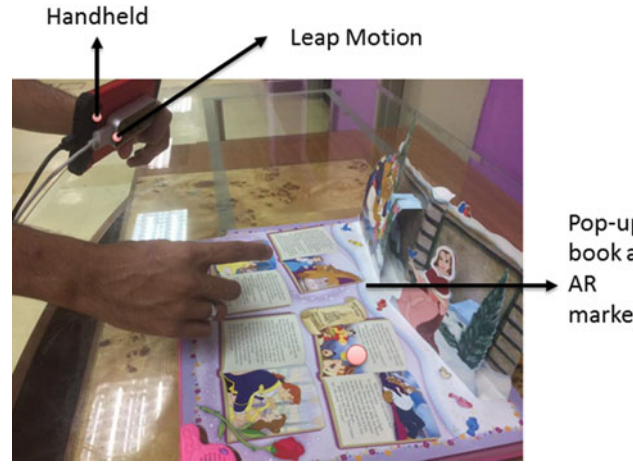
but in the transformation to more digital and interactive experience, the book offers a lot more than just a pile of heavy paper. Digital books recently have been widely restructured and recycled, yet it enhances the reading experience and more interactive than the conventional printed books. The main advantages of a digital book are that it can be customized to meet the reader's prospect (Markouzis and Fessakis 2015). This phase is conducted to design and construct the 3D contents for AR pop-up book. The 3D object built with animation is developed during this phase since the physical pop-up book does not in a digital mode. It was a fully printed copy.

An interactive storytelling enables user to take part and affects the plot of the story, creating a new genre of narrations that is much more engaging and adaptive. Several levels of interactive storytelling start from a simple branching plot to fully dynamic narration models. Interactive storytelling constitutes a new genre of literature which promises considerable learning effectiveness. This stage also defined that the appropriate 3D animation could be applied on the virtual object so the visual is more appealing and interesting. However, the storytelling has been chosen based on the current available conventional pop-up book which is entitled *Beauty and the Beast*. The physical fairytale pop-up book is being used to provide pop-up book with the storytelling. Therefore, we were transforming the existing format for real pop-up book into AR transitional and tangible in order to measure the AR experience.

Phase 2: Setting Up AR-Handheld User Interface

The phase is carried out that includes determining the display technique, tracking technique, and interaction method. This stage focuses on setting up the handheld AR interface as shown in Fig. 1. The user interface for AR application that uses the "pop-up book" metaphor has been designed. In order to create a good AR presentation, ensuring the virtual environment was displayed in a correct alignment to merge with real environment. This stage is the crucial part. Next, the display technique that was chosen is a handheld display device. The tracking technique that has been applied in this project is a feature-based. Feature-based tracking technique involves the registration of the virtual element on top of the real marker. Sensor-based was used in this project since it required the depth data to recognize the user's real hand gesture features. These elements have been prepared and examined to proceed with the next stage, the development of the AR pop-up book.

As illustrated in the diagram, it can be seen the hardware configuration. In order to overlay the virtual element on the top of real environment, the data of 3D object are loaded binding with 2D textures. In order to display the AR interface,



Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 1 Setting up of the AR-handheld interface

Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 2 Natural feature tracking process. (**a**) RGB image. (**b**) Gray-scale image. (**c**) Feature points

handheld device is chosen as AR display technology. The standard vision-based tracking system works to recognize the input, marker, and user hand. It recognizes the registered marker before it was loaded with the appropriate 3D object onto the scene. The user's hand required to be captured by the leap motion device (Guna et al. 2014). User interacts with the AR environment by using their bare hand as an interaction tool. The application is able to recognize user's one hand to interact with the virtual object, and the other hand holds the handheld device. Users can interact with the virtual animation by performing a define gesture that is recognized by the system.

Phase 3: Pop-Up Book Feature Tracking

This phase is conducted to design and construct the 3D contents for AR pop-up book. The 3D object built with animation is developed during this phase since the physical pop-up book does not in a digital mode. It was a fully printed copy. The phase is carried out that includes determining the display technique, tracking technique, and interaction method.

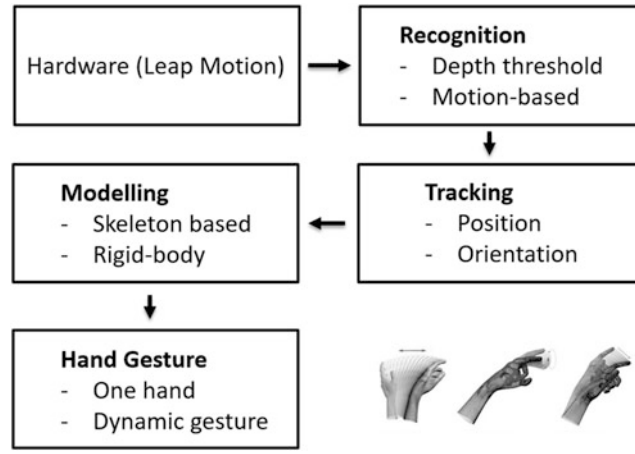
The main challenge in AR pop-up book application is to ensure the registrations and hand tracking problem are effectively solved. AR pop-up book utilizes the benefit of hand gesture recognition technique as an interaction tool in the AR environment. The tracking library is used to track the page of the pop-up book that utilizes a feature-based tracking technique.

Figure 2 shows the natural feature tracking process. The original RGB image is captured and converted to features so it will be recognized by the camera as the target image. Printed-colored image in Fig. 2a shows the original state of the marker. The marker then will be converted into gray scale using image processing to gray-scale format as shown in Fig. 2b before it is being processed as image target in the form of features as shown in Fig. 2c. The features were recognized by the system as a unique identification. The system will detect the marker and register the marker with a virtual element. The virtual cube, for example, will appear on the top of the marker after the camera recognizes the marker. The AR user interface was using this tracking process to display animation on the top of pop-up book. The edges of real pop-up book are being converted into features for this project.

Phase 4: Developing Hand Gesture Interaction

This phase focuses on exploring the gesture interaction for the user to interact with AR pop-up book. The study of the pop-up book concept and its interactivity processes has been carried out in Phase 3. In order to enhance the realism in AR environment for conventional pop-up book, we merge the AR pop-up book with the live character, and the story elements of the pop-up book come alive. The character will follow user's hand movement, and the story elements will activate the animation effects once user's hands touch them. To actualize this realism effects, user interaction is crucial to precisely hit the characters. To look more natural, the user can use their bare hands to directly contact with the virtual elements.

Therefore, hand gesture recognition method is one of the crucial parts in this project as it acts as the input metaphor for the user to interact with the virtual object in AR environment. Sensor-based



Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 3 Hand gesture recognition method

tracking device, leap motion, allows the application to read depth data and is able to track the position of user's hand in real world and mapping it into the virtual world (Guna et al. 2014). 3D hand skeleton-based interaction uses a leap motion sensor attached in front or back of a mobile device to provide simultaneous manipulations of 3D AR objects. By capturing the hand skeleton and identifying 3D finger positions and orientations, we can support a more natural hand gesture-based interaction in an AR scene. In addition to the 3D translation-only tasks in the previous works, simultaneous 3D translation and 3D rotation are possible to alter the location, pose, and size of virtual objects with hand gestures. As shown in Fig. 3, sensor-based tracking device, leap motion, allows the application to read depth data during recognition. Then, the device produces positions and orientations. It runs to track the position of user's hand in real world and to map it into the virtual world. To display virtual hand skeleton, the modeling process is required, and to enable interaction cues, the rigid body was applied to the 3D model of virtual hands. Once this process was completed, the gesture inputs are created.

Natural Gesture Interaction

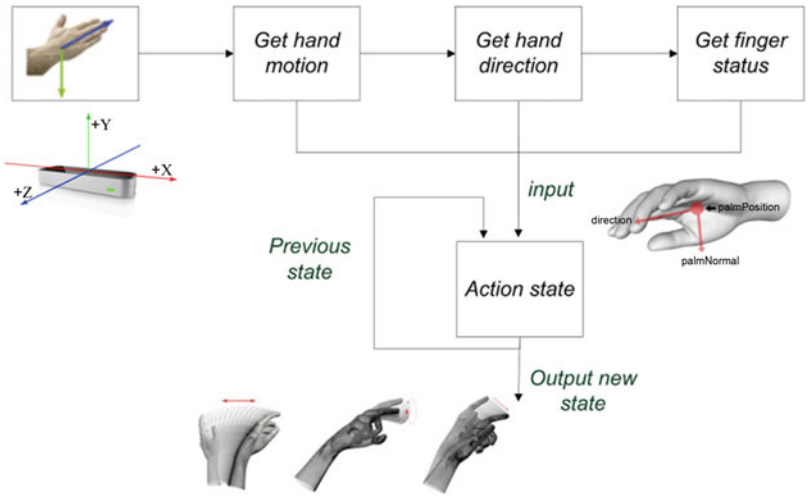
This section explains on natural gesture interaction which was divided into the following process.

Phase 1: Acquiring Gesture Inputs

There are three gesture inputs that have been defined such as TouchGesture, SwipeGesture, and CircleGesture. TouchGesture represents a virtual object that will call an appropriate animation as a feedback once it is being touched. SwipeGesture represents a virtual object that is being swiped, while CircleGesture is being retrieved and updated whenever user performed a circling gesture at designated position in the AR environment and call appropriate animation.

Figure 4 shows the flow of acquiring gesture inputs. The process starts when a leap motion device detects the hand interaction from the user using the sensor, and the gestures are identified in the pose detection. Then, the signal is sent to start the skeleton calibration that later leads to skeleton tracking. In this project, gestures used are grabbing to grasp object, pointing to select menu, palm up gesture to activate menu, and pinch to rescale the 3D object. The next process is to develop the natural gesture to interact with virtual object in AR pop-up book. In the next section, the real hand human gestures were captured by leap motion device, and recognition process was executed to obtain depth data from leap motion sensor-based tracking system.

The SwipeGesture is a gesture input where the user swipes their index finger to interact with the virtual object of the AR environment. The gesture is defined in this particular project by calculating the velocity and speed of the tip of the index finger

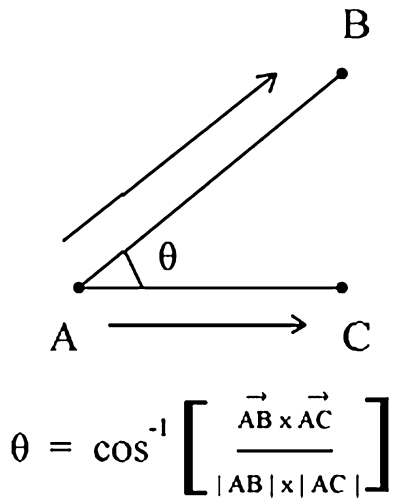


Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 4 Flow of acquiring gesture inputs

and the collision detection between the finger and the virtual object that can be interacted with.

The CircleGesture is a gesture input where the user makes a circling gesture by using their index finger to enable certain features in the AR environment in order to interact with the virtual object. The gesture is defined by calculating the vector, magnitude, and angle of the circle based on the position of the tip of the index finger of the user. Figure 5 is executed to calculate the angle.

The TouchGesture is a gesture input where the user touches the virtual object by using their index finger to enable certain features in the AR environment and interact with the virtual object. The gesture is defined in this particular project by making collision detection whenever the tip of the index finger collider of the user collides with the interactable virtual object in the AR environment.



Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 5 Flow of acquiring gesture inputs

Phase 2: Integrating Gesture with Handheld AR

In this phase, the gesture interaction technique is then integrated with the handheld AR scene. The hand gesture interaction technique has been developed for the user to interact with the AR pop-up book. In order to transmit the signal from the leap motion gesture tracking device to the application, we need to use Internet protocol. To actualize this, we enable the multiplayer networking as shown in Fig. 6. The network protocol in PUN (Photon Unity Networking) (Network 2015) is used, so we can send and receive gesture inputs to the AR handheld application.

Through the PUN network protocol that is being implemented in this stage, the user hand tracking data (position and rotation) from the real world is being sent by desktop (sender) to the handheld device (client or receiver). Photon network always uses a master server and one or more game servers. The master server manages the currently available games and does matchmaking. Once a room is found or created,

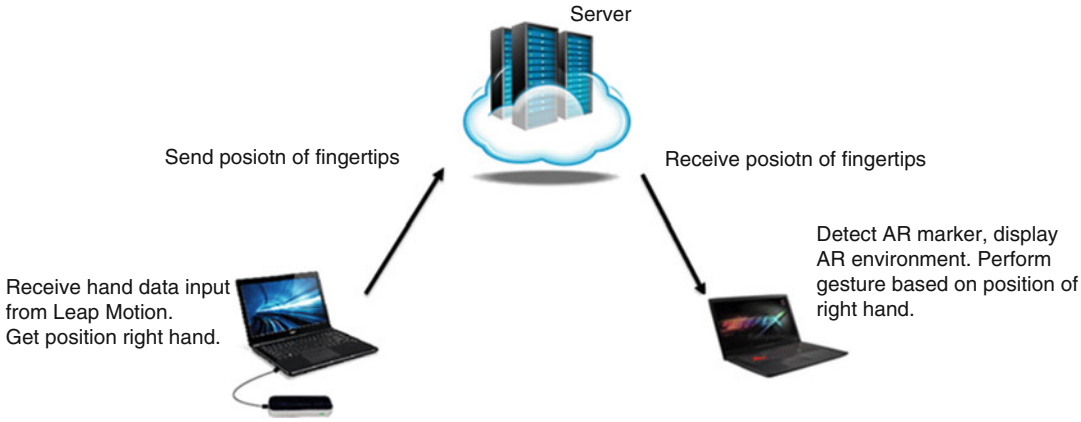
the actual gameplay is done on a game server. All servers run on dedicated machines.

Phase 3: Executing Gesture Interaction in AR Pop-Up Book

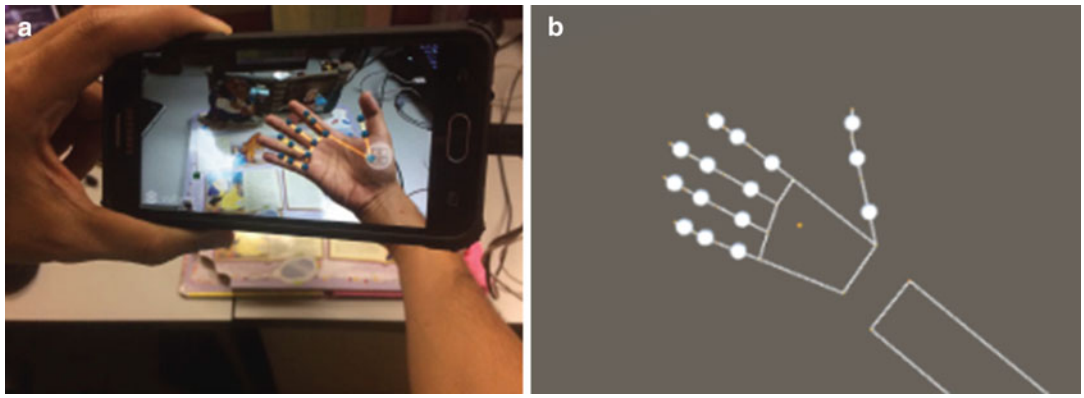
The leap motion is attached at the back of the smartphone, and the leap motion needs to be triggered and well-connected. It is necessary to enable the hand tracking and gesture interaction. Gesture recognition can be achieved by using the leap motion controller. It detects the hand gesture or hand signal as shown in Fig. 7. The hand gesture in the real world is recognized by the controller as shown in Fig. 7a, while the hand gesture in the virtual world is produced as shown in Fig. 7b.

The virtual hand is the representative of the real hand. Each gesture that is detected by the leap motion sensor can be seen in the monitor. Thus, every hand gesture such as swiping, pinching, or pointing in the real world is replaced by the virtual hand. This is done to ease the system development and give the user an immersive feeling or realism. Handheld device captures the user's bare hand to work with real hand gesture in handheld AR scene as presented in Fig. 8.

The handheld device's camera has synchronized the video input (720 HD pixel resolutions, 25 frames per second). It was placed in single alignment with the physical pop-up book (image of the marker) and the leap motion device which is attached to the handheld device (Android


Server
Send posiotn of fingertips
Receive posiotn of fingertips
Detect AR marker, display AR environment. Perform gesture based on position of right hand.
Receive hand data input from Leap Motion. Get position right hand.

Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 6 Flow of data transmitting using PUN



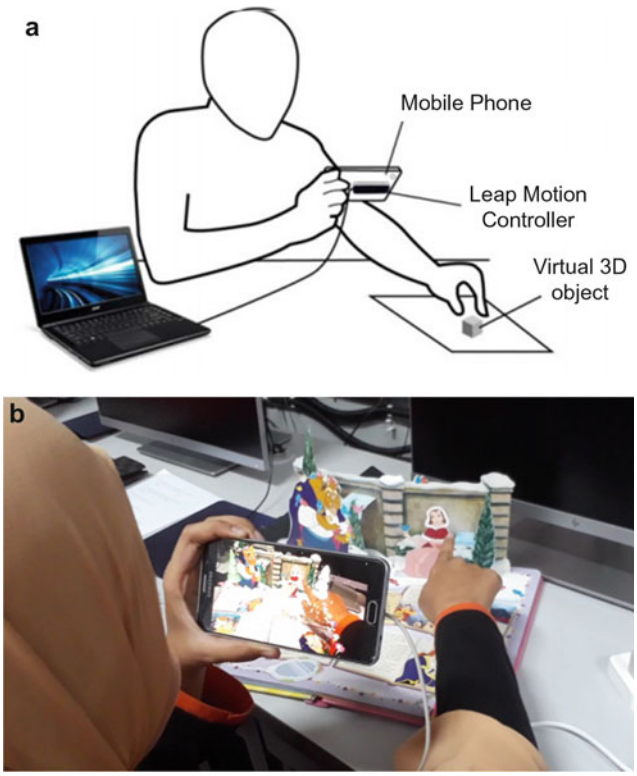
Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 7 Gesture signal transferred to handheld device. (**a**) Real hand gesture. (**b**) Virtual gesture inputs

Samsung), respectively, to detect the user's real hand skeleton as shown in Fig. 9a. A handheld screen displayed the viewing of AR scene. On the top of the table, the pop-up book was demonstrated with the user's fingertip as a controller to get the reference point of the augmentation as presented in Fig. 9b.

Problems and Restriction

The AR pop-up book is demonstrated in this entry as an interactive AR environment that enables users to play with the storytelling. The gesture interaction provides the user to directly interact with the virtual objects. The user feels more

Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 8 Gesture signal transferred to handheld device



Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld, Fig. 9 AR pop-up book in handheld screen. (**a**) User interacts with AR pop-up book. (**b**) Swipe the gesture, it will bring character alive

realistic to interact with 3D objects using their bare hands, and the realism of the 3D objects appears on the top of the pop-up book in the real world. Hence, there are several problems that arise regarding the real-time 3D gesture sensing in AR pop-up book. The first problem is the accuracy of the hand's detection because when the hands move into a certain position, it loses the accuracy. Accuracy in tracking is vital to ensure intuitive user interaction with the virtual elements (Lv et al. 2015). The second problem is that the user feels detached from the AR environment because of the indirect interaction method. However, these problems still persist especially when involving the precision of the hand's detection which can cause problem in the performance. It is natural that collision between the human hand and the augmented object can occur when manipulating the virtual 3D object. In AR, however, the collision happened between a virtual object and a real object; thus, the collision detection approach may be different compared with the ways in the real world. In the user's observation, with a handheld, the screens are often restricted and sometimes can be rotated between portrait and landscape. Handheld is small enough to hold and operate in the hand; nevertheless the user cannot use their both hands since the other hand needs to hold the device.

Based on the development stages described in the previous section, the standard guidelines emphasize on developing the handheld AR interface for AR pop-up book application that applies natural gesture interaction instead of touchscreen. The AR pop-up book development is explained in this entry but does not study the education pedagogy and the development stresses on AR technology to bring the physical book into more appealing and interesting handheld AR application. On the physical book, the virtual environment was overlaid in real time. The study on education purposes can be further explored the potentials and future work. Also, more future work in user's interaction for usability aspect can be carried out such as invoking the multimodal interaction that may bring AR pop-up book to be more interactive when speech input complements the gesture. Multimodal interaction is seen to advance interaction technique in AR which can improve user's experience in AR (Ismail and Sunar 2014; Piumsomboon et al. 2014). Handheld AR has been widely used with smart and portable device in the applications such as education, games, visual experience, and information visualization. However, most of the handheld applications have used touch-based to interact. Subsequently, the real hand gesture tracking in handheld AR is explored to examine how it tracks user's hands in real time. This entry describes the gesture interaction that allows the user to directly interact with the virtual objects. Thus, the user feels more realistic to interact with 3D objects using their bare hands.

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Interactive Augmented Reality to Support Education

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Synonyms

Augmented reality; Human-computer interaction

Definition

Augmented reality is a technology adding virtual objects to real environment through which enabling the fusion of missing information in real life. More formally, AR has been defined as a system that fulfills three characteristics (Azuma 1997). First, it combines the real and virtual world. Second, it allows real-time interaction. Third, it aligns real objects or places and digital information in 3D.

Introduction

Augmented reality has the potential to change how people interact and experience their surrounding environment (Sommerauer and Muller 2014). It is well known that interaction in education could result in better learning effect. Active involvement in learning, in the sense of being engaged, interacting, and taking part, is central to its effectiveness. To this end, a variety of computer-based activities have been developed with the aim of augmenting and extending active learning.

Nowadays augmented reality technology is emerging rapidly in educational and presentational area, such as augmented reality books, mixed reality books, AR contents in exhibitions, and AR applications in different disciplines, classroom, and laboratory. Usually, these contents will be used in classroom or in exhibition with multiple users at the same time and who usually have different background; so it is important to provide the users with a friendly, stable, and low-cost interface.

In these circumstances, tangible interface (Billinghurst et al. 2005)-based interaction for augmented reality could be a good choice.

Therefore, in this paper, authors combs the literature research related to AR support education and focuses on the combination of interactive AR and education in a variety of technical mean;, it is excepted that there could be a general interpretation of the application of interactive AR in education.

The Educational Research on AR-Supported Education

In 2010, Johnson et al. proposed AR technology as a key educational technology for the next 5 years (Johnson et al. 2010).

Santoso, Yan, and Gook from the Institute of Ambient Intelligence (IAI) work together with Sungsan Elementary School (SES) by developing a digital edutainment content based on Tangram toy as an existed edutainment media (Santoso et al. 2012).

Researchers also considered the AR technology to be integrated in the physical classroom environment (Bujak et al. 2013) and proposed AR design principles for classroom (Cuendet et al. 2013).

In 2014, Mhd Wael Bazzaza, Buti Al Delail, and M. Jamal Zemerly describes in their paper how an immersive augmented reality (iAR) application in conjunction with a book can act as a new smart learning method by engaging as many of the user's senses and human functions as possible (Bazzaza et al. 2014).

Through the applications of augmented reality, users can interact with virtual objects that are interposed on real scenes around them and obtain the most natural and genuine human–computer interaction experience (Cai et al. 2014).

In 2015, Murat Akçayır and other collaborators investigated the effects of the use of augmented reality (AR) technologies in science laboratories on university students' laboratory skills and attitudes toward laboratories (Clark et al. 2011). In 2016, Tien-Chi Huang, Chia-Chen Chen, and Yu-Wen Chou, based on Kolb's experiential learning theory, they develop an eco-discovery AR-based learning model (EDALM) which is implemented in an eco-discovery AR-based learning system (EDALS) (Huang et al. 2016).

Application of AR Technology in Different Disciplines

Many researches and developments had been made to apply AR technology in different disciplines; in this section, some applications were presented.

1. In a chemistry course

   Su Cai, Xu Wang, and Feng-Kuang Chiang, the three researchers, designed and developed a set of inquiry-based augmented reality learning tools. Students could control, combine, and interact with a 3D model of microparticles using markers and conduct a series of inquiry-based experiments (Cai et al. 2014).
2. Botany

   Based on Kolb's experiential learning theory, Huang et al. develop an eco-discovery AR-based learning model (EDALM) which is implemented in an eco-discovery AR-based learning system (EDALS). In a field experiment at a botanical garden, 21 middle school students constitute three groups participated in a learning activity using different learning types and media (Huang et al. 2016).
3. Mathematics

   In 2014, Peter Sommerauer and Oliver Müller designed and conducted a pretest–posttest crossover field experiment with 101 participants at a mathematics exhibition to measure the effect of AR on acquiring and retaining mathematical knowledge in an informal learning environment. They hypothesized that visitors acquire more knowledge from augmented exhibits than from exhibits without AR (Sommerauer and Muller 2014).
4. Biology and Medical Science

   In 2012, Tang and Ou carried out an experiment using AR and mobile technologies as an assistant tool for learning butterfly ecology (Tarng et al. 2013).

   Sylvain Bernhardt et al. proposed a new approach to automatically register the reconstruction from an intraoperative CT acquisition with the static endoscopic view, by locating the endoscope tip in the volume data (Bernhardt et al. 2014).
5. Painting Appreciation

   Kuo-En Chang et al. designed an augmented reality auxiliary tool for painting appreciation. It's a mobile guide system that

integrates art appreciation instruction with augmented reality (AR) that was designed as an auxiliary tool for painting appreciation. After the experiment, they made the discovery that most of the visitors using the mobile AR-guide system elicited positive responses and acceptance attitudes (Clark and Dünser 2012). In 2016, an AR app for iOS named ARart could turn figures in painting works into animating portraits with vividly expression and posture.

6. Early Childhood Education

   In 2015, Rabia M. Yilmaz developed educational magic toys (EMT) with augmented reality technology. EMT has included puzzles, flash cards, and match cards to teach animals, fruits, vegetables, vehicles, objects, professions, colors, numbers, and shapes for children 5–6 years of age in early childhood education (Yilmaz 2016).

7. Physical Spaces

   Sara Price and Yvonne Rogers described an approach for developing digitally augmented physical spaces. They claim that getting children to interact with the physical world, resulting in relevant augmented digital information appearing and which can subsequently be interacted with, is what can facilitate active learning (Price and Rogers 2004).

8. History and Archeology

   Martín, Díaz, Cáceres, Gago, and Gibert presented an educational application called EnredaMadrid to cope with this complexity. The objective of EnredaMadrid is to teach the history of the city in the seventeenth century to students in the activity through previous online training and a later physical technological gymkhana (Martin et al. 2011).

   Ardito, Buono, Costabile, Lanzilotti, and Piccinno presented a MAR game called Explore! with the aim to support during a visit and explorations of middle school students to archeological sites in Italy. Huizenga, Admiraal, Akkerman, and Dam have conducted a research by integrating the MAR games called Frequency 1550. This hybrid reality game was developed by the Waag Society to facilitate children to gain historical knowledge about Medieval Amsterdam (Nincareana et al. 2013).

9. Language

   Rose and Billinghurst (1995), Barreira et al. (2012), Miyosawa et al. (2012), and Li, S. and Chen, Y. (2015) developed AR tools for teaching Japanese and English language to non-native speakers.

Interfaces and Interactions in AR for Education

Image/Marker Recognition Based e-Books

Augmented Reality Books

Mark Billinghurst introduced augmented books resembling print books except that their pages have virtual graphics superimposed on them. The virtual content can provide an animated scene that complements print content and, in some cases, supports simple interactivity (Billinghurst and Dunser 2012).

Mixed Reality Book

Raphael Grasset, Andreas Dunser, and Mark Billinghurst focused creating a mixed reality book based on an already published book. With a *mixed reality book*, they propose to combine and seamlessly merge physical and virtual content in more meaningful ways. The representation of content can be either real or virtual or a mixture of both (Grasset et al. 2007).

Adrian Clark and Andreas Dünser present a new experience utilizing augmented reality-enhanced books. Users are able to color in the pages, and these pages are then recognized by the system and used to produce three-dimensional scenes and textured models reflecting the artwork created by the users. This three-dimensional virtual content is then overlaid on the real book pages, providing a three-dimensional experience using the users own content (Clark et al. 2011).

Multi-Marker-Based Interaction

Different from the single marker-based AR, the multi-marker-based AR could allow marks to

cooperate or interact with each other, one of which can be used as a trigger, when it is scanned, can trigger some interactive behavior, or can be used for experiment or game.

Su Cai, Xu Wang, and Feng-Kuang Chiang use the position of markers to present different phase of a structure and various combinations of atoms. The markers' behavior can be consistent with real particle behaviors in some cases while inconsistent in other cases. For example, when two markers get closer, a new molecule can be formulated, which is what really happens in microworld (Cai et al. 2014).

Zhang et al. (2017) developed tangible user interface elements based on multi-marker recognition for a scientific educational AR book, including virtual buttons, virtual rotate, and virtual hotspot. The user elements were integrated into various kinds of digital presentation systems by optimizing the logistic structure and interaction design of the user interface system to realize convenient spatial interactions.

The Markerless AR

Tai-Wei Kao and Huang-Chia Shih developed a markerless augmented reality (AR) applying for the picture books. They used the scale-invariant feature transform (SIFT) (Zhao and Ngo 2013; Zhao and Ngo 2013) to realize the markerless augmented reality application.

In order to reach the markerless mechanism, they identify the image contours using the point-matching algorithm: scale-invariant feature transform (SIFT) to deal with the black rectangular framing. The ARtoolkit is used to recognize the object from database and fetch the animations of the corresponding 3D objects. We collect images from the Internet to build the database and extract the SIFT features in advance (Kao and Shih 2013).

Mobile Device-Based Interactive AR for Education

Due to the rising popularity of mobile devices globally, the widespread use of AR on mobile devices such as smartphones and tablets has become a growing phenomenon (Nincarean et al. 2013).

Head-Mounted Displays (HMDs)

Head-mounted display is a kind of display which is worn on the head or as part of a helmet. It has a small display optic in front of one or each eye (Kesim and Ozarslan 2012).

In 2007, Arvanitis, Petrou, Knight, Savas, Sotiriou, and Gargalakos developed a project that is CONNECT; the CONNECT concept required student to wear a head-mounted display (HMD) and related computer-mediated learning platform in order to visualize and interact physically and intellectually with learning environment that deals with instructional materials, through "hands on" experimentation and "minds on" reflection. In addition, student can also perform experiments that are not possible in school. To evaluate the usability and effectiveness of the CONNECT project, a study has been conducted with learners with physical disabilities (Arvanitis et al. 2009).

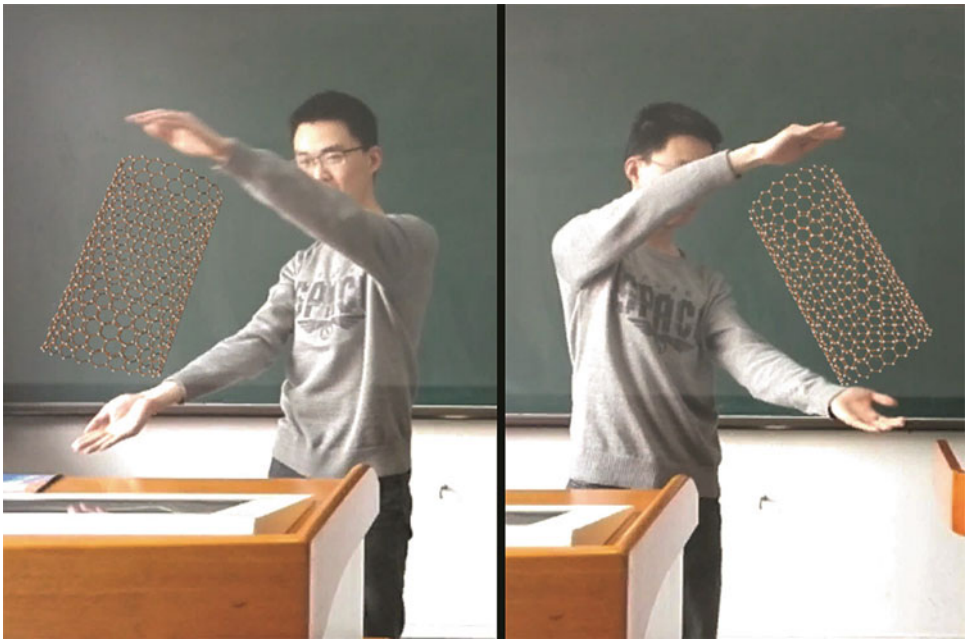
Handheld Displays

In 2009, Dunleavy, Dede, and Mitchell designed Alien Contact!, a MAR game that focus to teach math, language arts, and scientific literacy skills to middle and high school students. Alien Contact! was designed based on Massachusetts state standards and nurtures multiple higher-order thinking skills. When the students move around to their spot fields by using the Alien Contact! (Nincarean et al. 2013).

Location-Based Educational AR

The location-based AR systems use the position data of mobile devices, determined by the Global Positioning System (GPS) or WiFi-based positioning systems. The location-based AR systems enable users moving around with mobile devices in the real environment. Users can observe computer-generated information on the screens of mobile devices, while the information is triggered by the current location of the users in an environment.

CityViewAR is an example of unique experiential learning. Students can use this mobile phone application to walk through the city of Christchurch and "see" buildings as they were



Interactive Augmented Reality to Support Education, Fig. 1 Gesture-based interaction for classroom teaching (Source: Zhang and Zhu (2016). With permission from Springer)

before the 2011 earthquake made it necessary to demolish them.

Interact with Virtual Objects by Gesture

It will also be very wonderful to allow teacher to interact with virtual objects spatially, which could bring much more real feel and deeper immersive experience to the students also for the teacher.

Gesture-Based Interaction

It provides the teachers with a more effective way to communicating knowledge to the students by allowing the teachers to present the educational 3D contents interactively with spatial AR technology (Bimber and Raskar 2005). In this scenario, 3D virtual objects is displayed on a transparent projection screen that arranged in front of the podium, while students will see their teacher is interacting with the 3D virtual objects just like in the air, so the students could get much deeper immersive experience than that in traditional mode.

Zhang and Zhu (2016) build interaction between Kinect skeleton and virtual objects, which allow teacher to interact with virtual objects on transparent screen by using his hands or feet and achieve highly attractive performance. Figure 1 shows the process of a user interacting with a virtual object, zoom in or zoom out, move, and rotate them. Here, different gestures will be used to realize different manipulations.

Tangible Augmented Reality (TAR)

Tangible augmented reality (TAR) technology opens a novel realm which integrates the computer-generated elements into the real word. Its applications into design education have been explored with a limitation to this entire area (Chen and Wang 2008). In TAR systems, markers/tags can be added to the text to identify information related to the descriptions in the text and are detected with an image-processing tool, such as ARToolkit (Kato et al. 2000).

In 2008, Rui Chen and Xiangyu Wang presented and evaluated one TAR system to improve the pedagogical effectiveness of experiential and collaborative learning process in urban design education. For TAR systems, the initial mental image/model can be gained from reflective observation

(AR) and tactilely from tangible feedback (tangible interface) (Chen and Wang 2008). Chien-Huan Chien, Chien-Hsu Chen, and Tay Sheng Jeng had also applied TAR in their study; they aim to use augmented reality (AR) technology to create an interactive learning system, which helps medical students to understand and memorize the 3D anatomy structure easily with tangible augmented reality support (Chien et al. 2010).

Mark Billinghurst had enumerated the relevant examples in his paper:

> "Young children often fantasize about being swallowed up into the pages of a fairy tale and becoming part of the story. The MagicBook makes this fantasy a reality by using a normal book as the main interface object. People can turn the pages of the book, look at the pictures, and read the text without any additional technology. However, if they look at the pages through a handheld Augmented Reality display, they see three dimensional virtual models appearing out of the pages. The models appear attached to the real page, so users can see the AR scene from any perspective simply by moving themselves or the book." (Billinghurst et al. 2001b)

Interactive and Collaborative Education by AR

In natural face-to-face collaboration, people use speech, gesture, gaze, and nonverbal cues to attempt to communicate. In many cases, the surrounding physical world and objects also play an important role, particularly in design and spatial collaboration tasks (Billinghurst and Kato 2002). In a study by Bressler and Bodzin (Bressler and Bodzin 2013), middle school students collaboratively played an inquiry-based mobile AR game by using mobile devices to scan QR (quick response) codes to access game-related information, solve a detective case, and learn forensic science. The study reported that the group play of the vision-based AR game can increase students' science interest and their collaboration skills.

With the development of AR technology, it often be used to "shared space" system as a face-to-face collaboration tool, and it can be used to support remote collaboration, as well as the multiscale collaboration.

Face-to-Face Collaboration by AR

AR interfaces blend the physical and virtual worlds so real objects can interact with 3D digital content and improve users' shared understanding (Billinghurst and Kato 2002).

Hannes Kaufmann and Dieter Schmalstieg created various hybrid hardware setups, in order to complement the diverse teacher–student interaction scenarios for educational environments, and it was used in classroom. The wearable AR kits are composed of back pack computer, stereoscopic see-through head-mounted display with camera, and custom pinch gloves for two-handed input. One kit can be worn by the teacher, and the second one is available for use by students. In addition, it is intended to be used by high school students and teachers in an interactive, collaborative manner and to blend seamlessly into an everyday classroom situation (Kaufmann and Schmalstieg 2003).

Remote Collaboration by AR

AR technology can also be used to support remote collaboration. Mark Billinghurst and Hirokazu Kato, in an AR conferencing interface they developed in 1998, demonstrated a user that wore a lightweight HMD (with camera) and could see a virtual image of a remote collaborator attached to a physical card as a life-size, live virtual video window.

Multiscale Collaboration by AR

AR techniques can also be used to support multiscale collaboration, where users collaboratively view a data set from different viewpoints. Mark Billinghurst and Hirokazu Kato explored this in their MagicBook work (Billinghurst et al. 2001a). Individual users of the MagicBook interface have their own independent view of the content; any number of people can view and interact with a virtual model as easily as they interact with a real object (Billinghurst and Kato 2002).

Conclusion and Discussion

In this paper, the authors summarized the applications of AR technology in the field of education and tried to give an outline of the support and influence of interactive AR on education.

With the rapid development of AR technology and the popularization of AR device, AR could bring very wide space for education, the possibilities of AR interactions for education will be explored more and more, and also the utilization of AR in different disciplines will be deeper and deeper.

However, compared to other more mature technologies that were applied in education, it is still not so easy to use AR in education; AR creation usually needs many technical abilities such as programming and 3D modeling and more, but it is very difficult for normal teachers to utilize so many technologies, while programmers are usually not familiar with educational contents and the needs of interaction design from educational principles. So an excellent AR educational application should be the result of convergence team works of teachers, educational researchers, and technical experts and programmers.

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Interactive Computer Graphics and Model-View-Controller Architecture

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Synonyms

Model-view-controller (MVC); MVC architecture; MVC design pattern

Definition

Interactive graphics applications are a class of application that allows users to interactively update their internal states. These applications provide real-time visualization of their internal states with computer graphics. The model-view-controller (MVC) architecture is effective for presenting, discussing, understanding, and implementing this type of application.

As illustrated in Fig. 1, the **Model** contains the application state, the **View** renders the model graphically, and the **Controller** modifies the model. A **User** interacts with the MVC system by observing the content of the view and manipulating the controller to alter the state of the application.

Implementation Considerations

The model defines the persistent application state and implements interface functions which allow it to be modified. The model implementation should be independent from the technologies that build the view and controller components. For example,

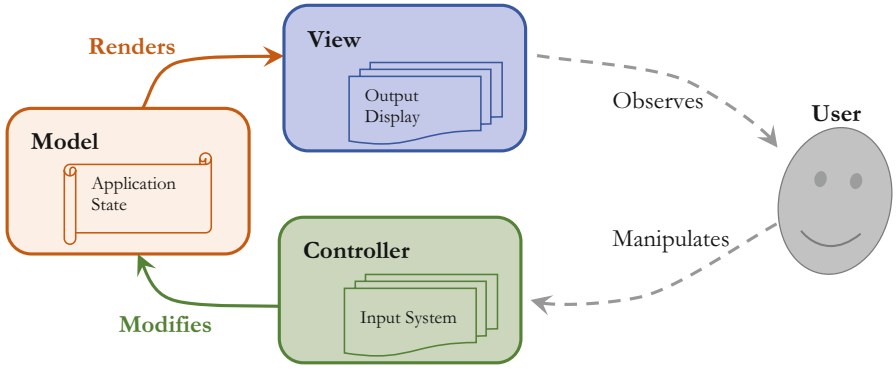
the model of an image editing application should consist only of data structures and algorithms for defining and maintaining the abstract content of images. In this way, different views and controllers based on distinct libraries can be defined and implemented for the same model. For example, view/controller implementations for a PC-version and a Mac-version are based on the same model.

One important benefit of the MVC architecture is the clear enforcement of separation between state modification and visualization. During state modification, the controller receives user input and triggers the model to modify the application state. The MVC architecture ensures that the application state rendering is a completely separate process involving the model triggering the view. During this visualization stage, the application state should be read-only and should not be changed.

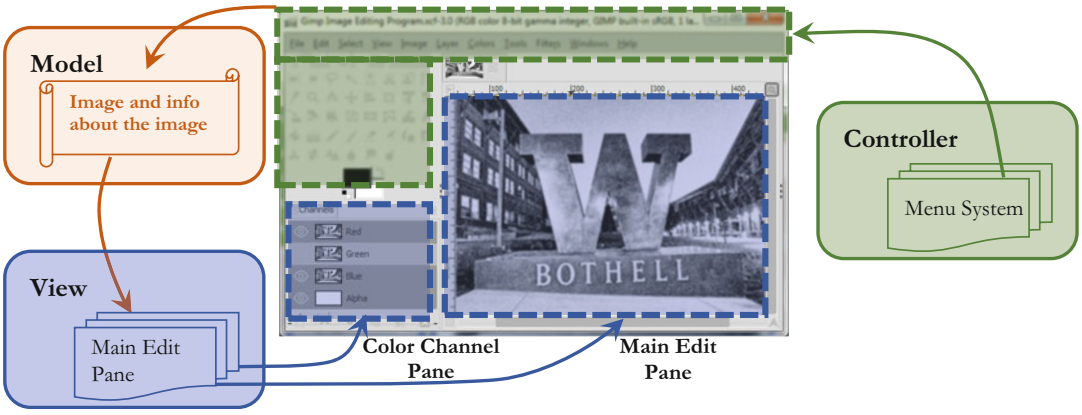
Figure 2 illustrates understanding GIMP, an image editor, as an MVC application. In this case, the Model (in orange), or the application state, is simply the image and information about the image. The view (in blue) renders and visualizes the application state as different panes in the application window, and the controller (in green) provides the interface for the user to manipulate and update the image.

Context of Video Games

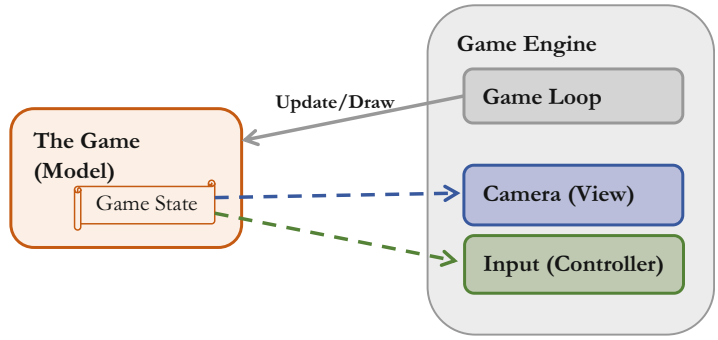
Modern video games are examples of interactive graphical applications. Typically, games are built based on specific game engines. As illustrated in



Interactive Computer Graphics and Model-View-Controller Architecture, Fig. 1 The model-view-controller architecture



Interactive Computer Graphics and Model-View-Controller Architecture, Fig. 2 GIMP (an image editor) as an example MVC application



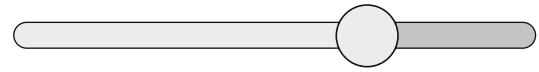
Interactive Computer Graphics and Model-View-Controller Architecture, Fig. 3 Modern video games and the MVC architecture

Fig. 3, the game loop sub-system in the game engine periodically triggers the game to update and draw its state. In response, the game invokes the game engine functionality: the camera sub-system to render, and input sub-system to receive user commands. In this way, the game is the model responsible for defining and maintaining the game state, and the view and controller functionality are provided by the game engine.

Considering a video game as an MVC application ensures the separation of state update and draw operations. Game state should only be modified during the game engine update call, and only rendered during the game engine draw call. As discussed in the game loop implementation, the update and draw call frequencies are typically independent and can vary with the underlying system performance. Any attempts to draw the game state during update cycles or change the game state during draw cycles can easily result in a chaotic and unmanageable system.

Applying the MVC

It is interesting that the MVC architecture can be applied to interactive graphical systems of any scale. For example, the slider bar shown in Fig. 4 is a fully functional graphical interactive system. In this case, the model is a numeric value (typically a floating-point number), the view presents the numeric value to the user, and the controller allows the user to interactively modify the value. A typical view draws icons (bar and knobs) representing the range and current value in the model, whereas the



Interactive Computer Graphics and Model-View-Controller Architecture, Fig. 4 A Unity3D slider bar

controller typically supports mouse down and drag events to interactively modify the value in the model component. A slider bar implementation can choose to include an additional view by echoing the numeric value in a separate textbox. The corresponding controller would allow the user to modify the numeric value in the textbox. When the typing functionality is disabled, the view exists without a corresponding controller.

Cross-References

- ▶ Character Animation Scripting Environment
- ▶ Decoupling Game Tool GUIs from Core Editing Operations
- ▶ Game Engine
- ▶ Game Loop and Typical Implementation
- ▶ Physical, Virtual, and Game World Persistence

Interactive Design

- ▶ 3D Room Layout System Using IEC (Interactive Evaluational Computation)
- ▶ Foundations of Interaction in the Virtual Reality Medium
- ▶ Virtual Reality Retailing

Interactive Digital Literature

▶ Hypermedia Narrative as a Tool for Serious Games

Interactive Displays

▶ Experiential Media: Using Machine Vision and Sensor-Input to Create Dynamic Real-Time Generated Media

Interactive Game

▶ King of Fighters, a Brief History

Interactive Game Design

▶ Biosensing in Interactive Art: A User-Centered Taxonomy

Interactive Genetic Algorithm

▶ 3D Room Layout System Using IEC (Interactive Evaluational Computation)

Interactive Learning

▶ Gamification and Social Robots in Education

Interactive Learning Events

▶ Gamification and Serious Games

Interactive Multimedia Narrative

▶ Hypermedia Narrative as a Tool for Serious Games

Interactive Multimedia Scenarios

▶ Timed Automata for Video Games and Interaction

Interactive Music

▶ Adaptive Music

Interactive Music Systems

▶ Dynamic Music Generation: Audio Analysis-Synthesis Methods

Interactive Narratives

▶ Narrative Design

Interactive Ray Tracing

▶ Ray Tracing in Video Games

Interactive Room Layout

▶ 3D Room Layout System Using IEC (Interactive Evaluational Computation)

Interactive Sound Design

▶ Biosensing in Interactive Art: A User-Centered Taxonomy

Interactive Storytelling

▶ Narrative Design

Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology

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Synonyms

CAVE; Cave automatic virtual environment

Definition

Although interactive systems already exist in the animation industry, nowadays there is not a system that combines an animated story and a virtual reality system complemented by the spectator's interaction, in order to tell that story properly.

Introduction

Over the years, animation has had a great impact on society. It has been used to entertain, but also to inspire, inform, and educate. In the last century, animation has been transformed in terms of finding new ways to achieve it. The use of new technologies has provided entirely new forms to appreciate this art form, such as computer animation, digital art, and virtual reality, among others.

Thus, the main objective of this project is to create an animated story that will use a CAVE, a holographic projection, and a tracking system as necessary tools to tell the story and not only as a way to project it. With the use of this technology, we are seeking to generate a similar or a better cinema-like viewing experience for the users.

In this entry, we will introduce the prototype of the first phase of our investigation. This small-scale prototype simulates the performance explained above. The goal is to test the response of the users to this prototype.

Brief Description of the Project

CAVE

A CAVE system is built using three different screens. Through the use of stereo glasses, the user is introduced to a three-dimensional environment.

Hologram

A light source originated from the top of the CAVE illuminates a contained reflective object. The diffraction generated from the interaction between the light and the object produces a computer-generated 3D holographic animation.

Tracking System

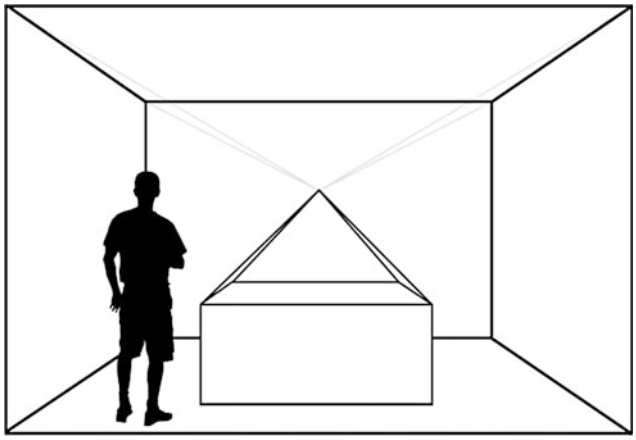
A tracking system captures the user's movement. The gestures generated with this system stimulate and put in action the holographic animation and the graphic elements inside the CAVE environment (Fig. 1).

The possibilities of how a story can be told are infinite, since there are lots of combinations that can be done between the use of the CAVE, the hologram, and the user's interaction.

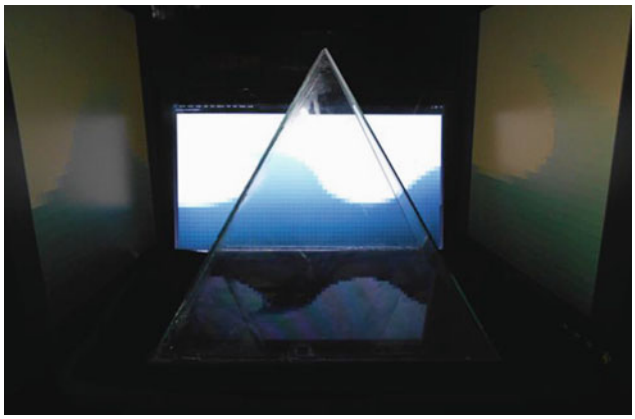
Description of the Prototype

The following elements were used in the creation of this prototype in order to simulate the performance of the project:

Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology,
Fig. 1 Diagram that illustrates the project



Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology,
Fig. 2 CAVE prototype



Three 18.5″ * 11.6″ Monitors

These monitors are used to simulate the CAVE (Fig. 2).

One 18.5″ * 11.6″ Monitor

This monitor is used as a light source above the CAVE to project the hologram.

Reflection System

A reflective pyramid used to simulate the holographic projection (Fig. 3).

A Leap Motion Controller

Used to track the user's gestures.

Overview

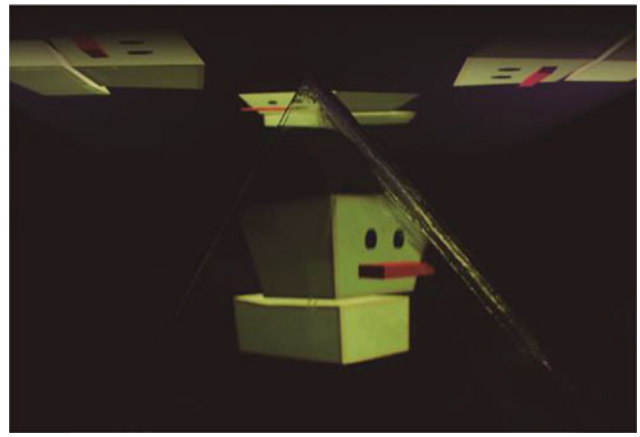
For this prototype we designed a Unity project. In this project there is a 3D model of an animal and an interactive voxelized environment (Fig. 4).

When the user makes a movement with his hand, the leap motion catches it and both, the animal and the environment, answer with an animation. The animal moves in its individual way according to which animal is being used (duck, firefly, or elephant). The user can change the animal by making another gesture. Since each animal has its unique voxelized environment, when the animal is changed, also thus the environment (Fig. 5).

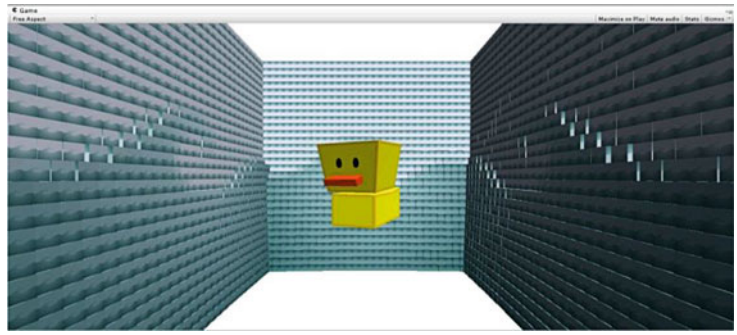
Experiments and Results

Fifty people tested the prototype (18–40 years).

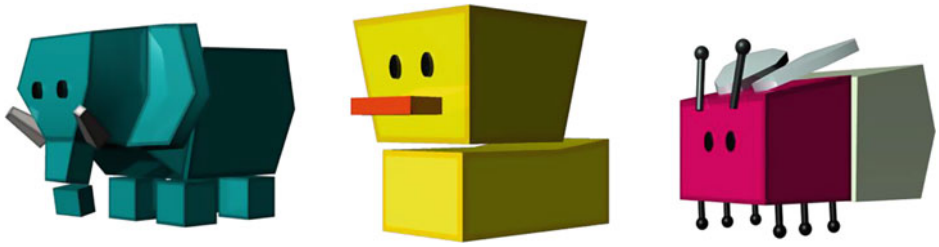
The obtained results were very positive in terms of interaction and entertainment.



Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology, Fig. 3 Holographic projection



Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology, Fig. 4 The Unity project

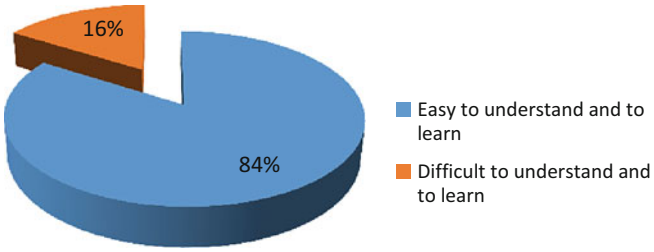


Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology, Fig. 5 Models used for the prototype

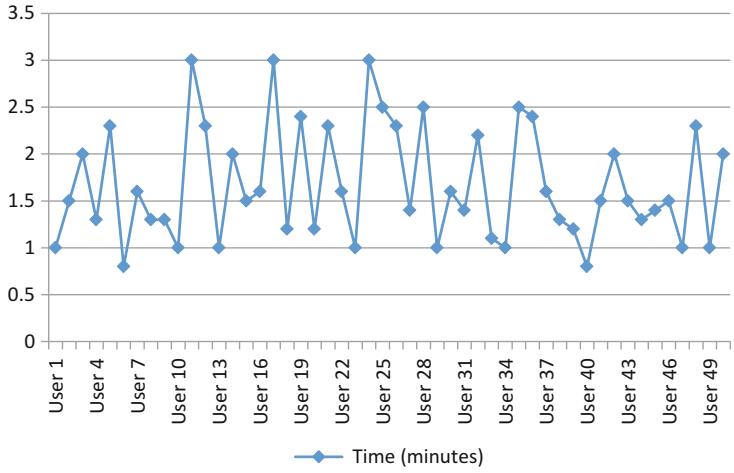
Ninety-five percent of the testers liked to be the directors of the actions that were projected in the CAVE (Fig. 6).

Eighty-five percent of the testers expressed that the interaction system was easy to understand and to learn (Figs. 7 and 8).

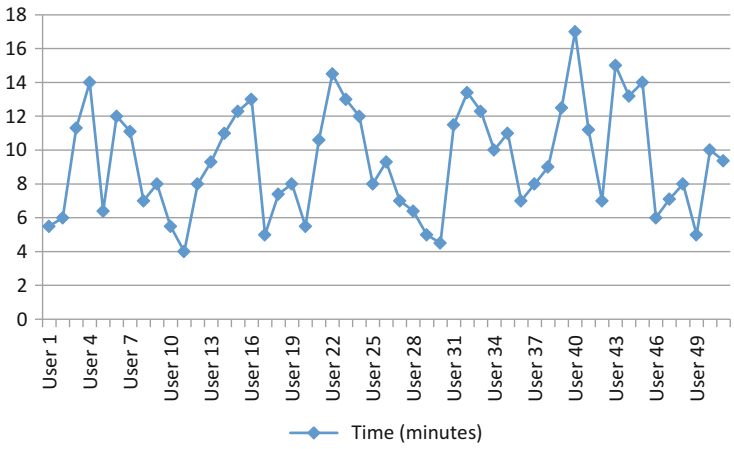
The average time that testers took to understand the functioning of the holographic and CAVE system was 1.67 min. Moreover, users were allowed to interact with the prototype for as long as they liked, and the average time was 9.3 min.



Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology, Fig. 6 Interactive design graph



Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology, Fig. 7 Time used to understand the system graphic



Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology, Fig. 8 Time that users liked to interact with the prototype

Eighty percent of the testers considered that the aspects of the prototype that could be improved are the number of actions that the user can make. This change would increase the possible stories or results, giving an illusion closer to the role of a storyteller.

Data indicates that the system was an easy one to understand and followed the interactive design; and very importantly, it proved to be entertaining for them.

Further Work

To create a whole animated story that uses the holographic projection and the CAVE in its narrative structure, then test the simulation with a real holographic projection in a real-scale CAVE with several users at the same time. This test will include:

- How the animated story functions in this platform
- User's response
- Different and new ways in which users could interact, since there will be several of them

Conclusion and Discussion

The use of new technologies can contribute a lot to storytelling. They provide to the artists different perspectives of how to push an animated project, in order to come up with more interactive and interesting results.

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Interior Design

▶ 3D-Rendered Images and Their Application in the Interior Design

Intrusion Detection System

▶ IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games

iPad Animation

▶ Exploring Innovative Technology: 2D Image Based Animation with the iPad

IPv6

▶ IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games

IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games

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Synonyms

Intrusion detection system; IPv6; Network security; Vulnerabilities

Definition

An Internet Protocol Version 6 (IPv6) is the most recent generation of Internet Protocol.

An Intrusion Detection System (IDS) is a device or software application that monitors a network for malicious activity or policy violations.

A Network Intrusion Detection Systems (NIDS) is a system that analyzes incoming network traffic.

Introduction

Our world has become a big network where everyone connects to it by the Internet. Most people living on the earth rely on this network. They are reading news, transferring money, and checking their emails and much more in their daily basic life. The goal of the new modern world is the availability, integrity, and confidentiality of this network. The rapid growth and widespread use of electronic devices and data processing (cloud computing, web application, Internet network, wireless networks, and private network) will raise the need for a solution that can provide a safe and secure infrastructure for a safe communication. To use the Internet, each device needs to have an Internet Protocol (IP) address. An IP address is a unique number that is assigned to every device that is connected to the network or Internet. The IP address enables devices to communicate with each other. There are two different versions of IPs, Internet Protocol Version 4 (IPv4) and Internet Protocol Version 6 (IPv6). IPv4 was developed in the early 1980s, but because of the rapid growth of the Internet, IPv4 has been fully allocated to Internet Services Providers and Internet users, and then there was a shortage of IPv4 available address (Icann 2011). IPv6 was standardized in 1996 to replace the current version of IPv4 and covers the biggest limitation of IPv4 which is the lack of enough addresses for all Internet users. In recent years, the major service providers have started to offer IPv6 addresses to their users (Icann 2011). Based on a report from Google on 16 Aug 2018, 23.91% of the users that access Google are over IPv6. This report shows how usage of IPv6 has grown during the last couple of years. With IP being the Internet's main protocol, many constitutive Internet technologies are heavily tied to it and the change to version 6 resulted in updates of related protocols (Fig. 1).

The major changes between IPv4 and IPv6 can described as:

- **IPv6 large address:**

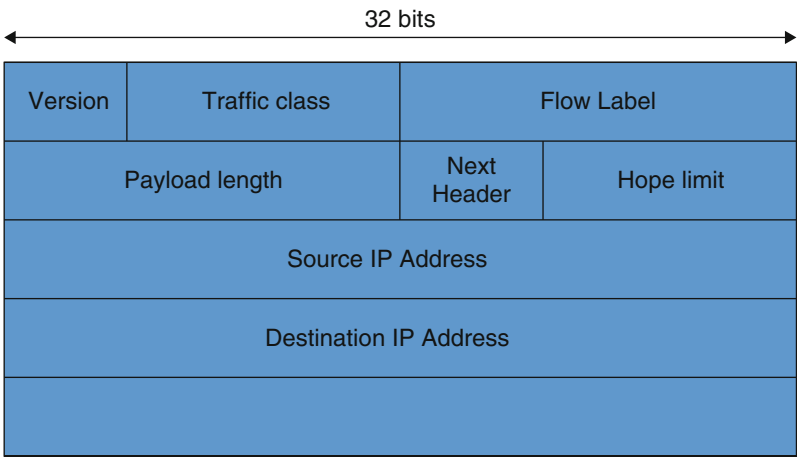
IPv6 is 128bit, this mean, it can provide 340 trillion, trillion, trillion IPv6 addresses. That means IPv6 uses 128bit address space.

- **IPv6 fragmentation:**

IPv6 is no longer required to be fragmented by the router. All fragmentation and reassembly are performed by sender and receiver host(s).

- **Addressing:**

IPv6 uses three types of addresses which are unicast, multicast, and anycast. Unicast is only assigned to a single node of IPv6; however, a



IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games, Fig. 1 IPv6 header

multicast is assigned to multiple nodes in a single multicast group.

- **Auto-configuration:**

New capabilities of IPv6 that allow a new node automatically configure IP addresses.

- **Extension headers:**

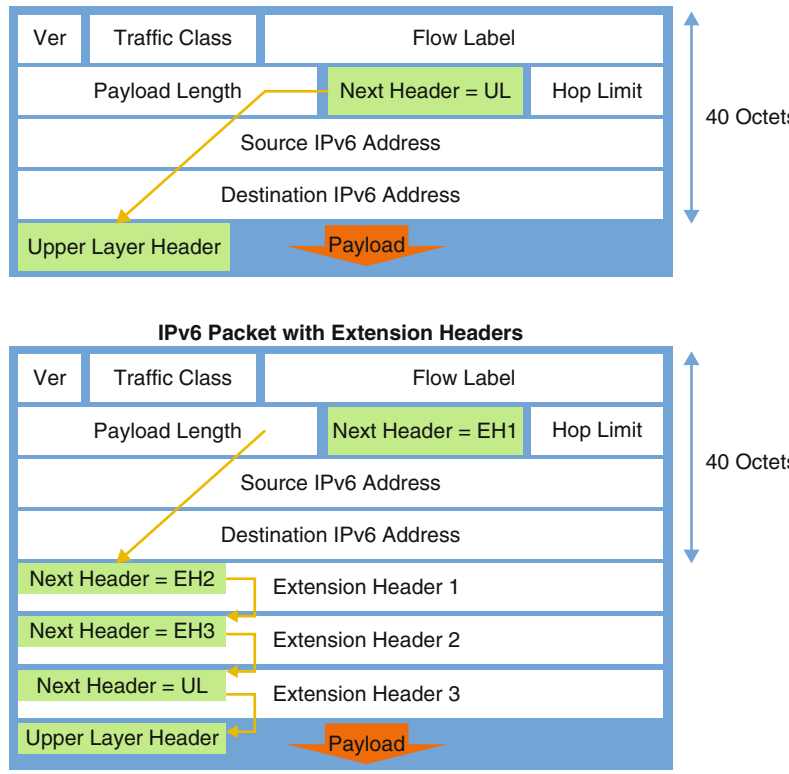
Referring to RFC 2460 (Deering and Hinden 1998), a full implementation must include support for six extension headers, which are Hop-by-Hop Options, Routing (Type 0), Fragment, Destination Options, Authentication Headers, and Encapsulating Security Payload.

Extension Headers

Apart from expanded addressing capabilities, one of the most important and significant changes in IPv6 is the improvement of supporting extension header with the options (Deering and Hinden1998). In IPv4, some of the header fields have been dropped to reduce the cost of packet handling and processing. However, this has been changed in IPv6 where the Extension Headers function is added. The Extension Headers are placed between IPv6 header and the upper layer header in a packet, and each of the Extension Headers is identified by a distinct next header value. As this is an optional field, each IPv6 packet can have zero, one, or more extension headers. Each Extension Headers have multiple of 8 octets long Fig. 2.

Internet Control Message Protocol Version 6 (ICMPv6)

Unlike ICMP for IPv4, ICMP for IPv6 (Conta and Deering 2006) play an important role in IPv6 network. ICMPv4 is not required in IPv4, but ICMPv6 is a required element and therefore it cannot be filtered completely. ICMPv6 has a next header value of 58. The main reason that ICMP was developed as a protocol was to be used for tests and diagnosis on IPv4 networks. The most important features that ICMP provides are to enable the utilities such as ping and trace



IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games, Fig. 2 IPv6 packet with extension header

route to help verify end-to-end IP communication and connectivity and provide information about any errors on the connection back to nodes (Davies and Mohacsi 2007). ICMPv6 messages can be categorized into two categories (Davies and Mohacsi 2007):

Error messages:

- 1 Destination Unreachable
- 2 Packet Too Big
- 3 Time Exceeded
- 4 Parameter Problem
- 100 Private experimentation
- 101 Private experimentation
- 127 Reserved for expansion of ICMPv6 error messages

Informational messages:

- 128 Echo Request
- 29 Echo Reply

Error messages will generate a report of any errors that occur during the message delivery. Informational messages will allow sharing of required information between nodes. As in other features, attackers may use ICMP for exploitation, and therefore sys-admin has no choice but to completely filter the protocol to prevent such attacks (DoS/DDoS, Evasion, Scan, Man in the Middle) (Davies and Mohacsi 2007). However, unlike ICMPv4, ICMPv6 cannot be filtered/blocked completely due to the important role that it plays in the IPv6 network. According to RFC 4890, filtering ICMPv6 on routers and firewalls is different from on a host. ICMPv6 is a required protocol on every IPv6 network. ICMPv6 provides the following functions (Davies and Mohacsi 2007):

- Neighbor Discovery Protocol (NDP), Neighbor Advertisements (NA), and Neighbor Solicitations (NS) provide the IPv6 equivalent of IPv4 Address Resolution Protocol (ARP) functionality.
- Router Advertisements (RA) and Router Solicitations (RS) help nodes determine information about their LAN, such as the network prefix, the default gateway, and other information that can help them communicate.
- Echo Request and Echo Reply support the Ping6 utility.
- PMTUD determines the proper MTU size for communications.
- Multicast Listener Discovery (MLD) provides IGMP-like functionality for communicating IP multicast join and leave.
- Multicast Router Discovery (MRD) discovers multicast routers.
- Node Information Query (NIQ) shares information about nodes between nodes.
- Secure Neighbor Discovery (SEND) helps secure communications between neighbors.
- Mobile IPv6 is used for mobile communications.

Neighbor Discovery Protocol (NDP)

As defined in RFC2461, Neighbor Discovery is a protocol for IPv6. Since Address Resolution Protocol (ARP) has been removed in IPv6, both hosts and routers use Neighbor Discovery messages to determine the link layer addresses of nodes on the local link. When a host is connected to an IPv6 network, it sends Router Solicitation messages to routers on the same link to get network information such as network prefix, default router, and other network parameters. Stateless Auto-Configuration is another feature based on Neighbor Discovery Protocol which allows new hosts on the local link to get and configure their IPv6 address (Thomson and Narten 2007) (Table 1).

The transition from IPv4 to IPv6 should have eliminated any related security issue to the new protocol. The security mechanisms for network layer protocol should be examined in many different areas. One of these areas is how Operating Systems handle the IPv6 fragmented packet and how Network Intrusion Detection Systems can detect an attack on the IPv6 network. If used properly by an attacker, this feature in IPv6 can lead to Network Intrusion Detection System (NIDS) evasion, Firewall evasion, Operating System fingerprint, Network Mapping, Denial of Service (DoS)/Distributed Denial of Service (DDoS) attack, and Remote code execution attack (Ptacek and Newsham 1998; Erickson 2007; Chen 2014; Reese 2009).

IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games, Table 1 Neighbor Discovery Protocol (NDP) messages

ICMPv6 type	Message name	Source address	Receiver address	Used for
133	Router Solicitation (RS)	Nodes (routers link local address)	FF02::2 (multicast address)	Sent by hosts to locate routers on attached link
134	Router Advertisement (RA)	Routers	Sender of RS or FF02::1	Routers advertise their presence and link prefixes, MTU, and hop limits
135	Neighbor Solicitation (NS)	Nodes	Solicited node multicast address or the target node's address	To query for other nodes link layer address and also used for duplicate address detection and to verify neighbor reachability
136	Neighbor Advertisement (NA)	Nodes	In response to NS sender or to FF02::1	In response to NS query
137	Redirect	Routers	Link local address	To inform other nodes for better next hop routers

IPv6 Vulnerabilities

Despite the security improvements in IPv6, some vulnerabilities are still common between IPv4 and IPv6. Insertion, Evasion, and Denial of Service are three different categories of attacks, which were proposed by Ptacek and Newsham (1998) for the first time. Most of the vulnerabilities are common between IPv4 and IPv6 (Mali et al. 2015; Satrya et al. 2015; Tripathi and Mehtre 2013), and because of the changes that were made in the IPv6 implantation (Deering and Hinden 1998), additional vulnerabilities arise as well. There are many features which are new and unique to IPv6. One of them is the improved support of headers (extensions and options) which were not existing before in IPv4.

Insertion, Evasion, and Denial of Service are three different categories of attacks, which were proposed by Ptacek and Newsham (1998) for the first time. The aim of these attacks is to make the IDS or victim host process different data or process the same data but differently. By using an insertion attack, IDS accepts a packet(s) that is rejected by the host. The packet looks valid only to the IDS. The attacker can bypass the signature-based IDS by inserting the traffic in such way that the signature is never matched or found. This process is different in Evasion attack; in Evasion attack the IDS rejects the packet that the end host accepts. The attacker can send some or all malicious traffic into the network without being caught by the IDS.

IPv6 Fragmentation Attack

Referring to all the aforementioned (RFC2460, 1998; RFC 3964, 2004; RFC 7123, 2014) recommendations of corresponding IPv6 Requests for Comment (RFCs) and previous sections, when using IPv6 Extension Headers and IPv6 Fragmentation, there are potential attacks against the Operating System (OS). In case of discrepancies between the behavior of several OS, this can lead to OS fingerprinting, Intrusion Detection System (IDS) insertion and IDS evasion, and Firewall evasion. Furthermore, there are still some issues regarding the handling of the IPv6 fragments (Atlasis 2012). One of the simplest examples of the one of the most common attacks can be fragmentation attack, which is common between IPv4 and IPv6 (Atlasis 2017).

Several IPv6 fragmentation and overlapping methods were used to test the effectiveness of some of the most popular OS, and it is found that none of them is fully RFC compliant while most of them seem to have significant issues (Fig. 3).

IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games, Fig. 3 IPv6 fragmentation process

Operating System Fingerprint

This method is used for identification of the victim host. In human life, fingerprints can be used to identify a person. Similarly, an OS has its unique implementation of communication protocols by which it can be identified. In order to identify the OS and its version remotely and without having a direct access to that system, the attacker uses fingerprinting to analyze certain characteristic and network behavior communication (Eckstein and Atlasis 2011). By using such a method, the attacker can easily discover the live host on the network and identify their OS, and furthermore by using this method, the attacker could even reveal the victim host's missing security patches or service packs. As a result, the attacker can easily use the related vulnerability to gain access to and control the end host easily (Allen 2007).

ICMPv6 Flooding Attack

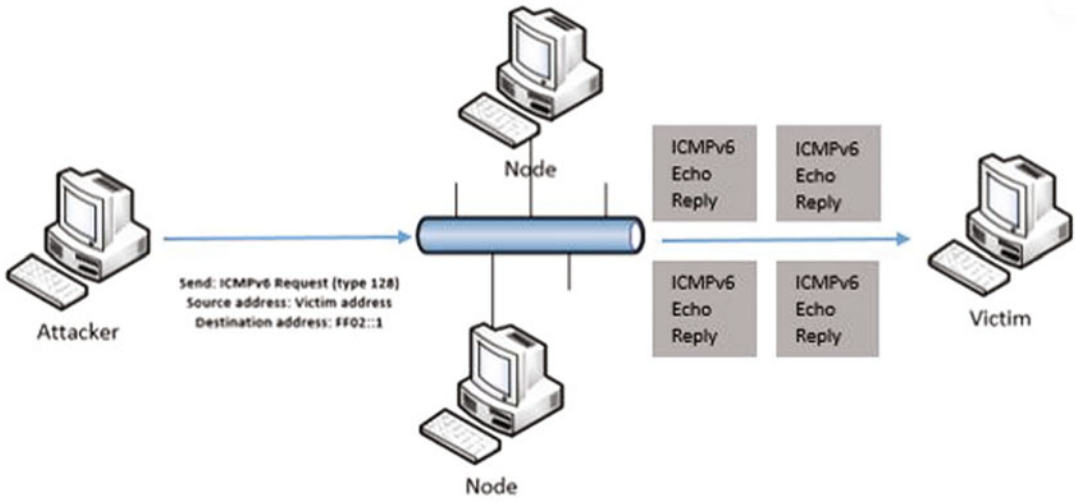
ICMPv6 flooding attack is one of the most common attacks in both IP versions. The aim of using ICMPv6 attack is to use all of a victim's resources (bandwidth, CPU, and RAM) by sending a large amount of traffic. The packet can contain any ICMPv6 type with source address referring to another node on the network (Martin and Dunn 2007).

To disturb the communications between routers and hosts, an attacker can use ICMPv6 error or informational messages such as ECHO (request and reply), Router Advertisement, Neighbor Advertisement, Neighbor Solicitation (NS), and Multicast Listener Discovery messages for a successful attack (Chen 2014).

ICMPv6 Amplification

The amplification attack is considered as one of the common security challenges in IPv4 and still exists in IPv6. The amplification attack allows the attackers to generate huge numbers of packets using a small number of packets and amplify it to a large number of packets based on the multicast address feature.

Broadcast Amplification attack also known as Smurf (Fig. 4) is the most well-known amplification attack, which is based on ICMPv6 multicast address function. The attacker uses Smurf attack to launch a DoS attack by sending an ECHO request packet to a multicast address with spoofed source address of victim machine. Once all nodes of the targeted multicast address have received a packet, all nodes start to reply to the source, which is the victim, and flood it with a large number of ECHO reply attacks. The victim will be overwhelmed and cannot respond to genuine requests (Martin and Dunn 2007). In addition, there is another version of Smurf attack which is called rSmurf (Remote Smurf) attack that has stronger amplification, because each packet generated by



IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games, Fig. 4 Smurf attack

rsmurf6 can generate a large number of packets on the remote LAN. As a result, one malicious packet will generate a storm of traffic on victim network.

ICMPv6 Protocol Exploitation

By sending a Router Advertisement (RA) packet, any node on a network can claim that they are a router. An attacker can use this feature of ICMPv6 to perform a Man in the Middle (MitM) attack by presenting themselves as a router. The first method an attacker can use to launch a Dos/DDoS attack is by using Router Discovery packets, which are Router Solicitation (ICMPv6 type 133) and Router Advertisement (ICMPv6 134). The second method will be using Neighbor Discovery (ICMPv6 types 135 and 136) packets. The third method will be using Redirect furcation (ICMPv6 type 137) packets.

The Router Discovery process is responsible for packet routing. On the IPv6 network, a host will find a router by sending a Router Solicitation packet to router multicast address (FF02::2). Once the Router Solicitation packet is received by the default router, in response to that packet, the router will send Router Advertisement to the host. The Router Advertisement packet contains the information needed by the host such as router specification, onlink prefix, and network parameter (Tripathi and Mehtre 2013). An attacker can misuse Router Solicitation and Router Advertisement packet and perform the following attacks:

- Default router is "killed": By default, every node has a router table to list all routers on the network. When a node does not have any record in the table, it will consider that all destinations are on link (Narten et al. 2007). Now an attacker can send a Router Advertisement packet with router lifetime equal to zero and spoofed address. When the host receives the Router Advertisement packet, it will delete the router record because of the lifetime, and then it will redirect all packets to the destination without a router address. If the traffic is going outside of network, all packets will be lost, and therefore an attack has occurred (Tripathi and Mehtre 2013).
- Bogus address configuration prefix attack: As mentioned earlier, one feature of IPv6 is that in absence of DHCP server, a node will generate their own IPv6 using Stateless Auto-Configuration with subnet prefixes of Router Advertisement messages that are received from a default router (Kempf and Nordmark 2004). The router sends Router Advertisement messages

accordingly to all nodes to update their routing table information. By sending a Router Advertisement message with invalid subnet prefix to multicast address (FF02::1), an attacker can launch an attack. Now all nodes will generate an invoice IPv6 address based on the invalid prefix that was received, and all communication between hosts will be disrupted.

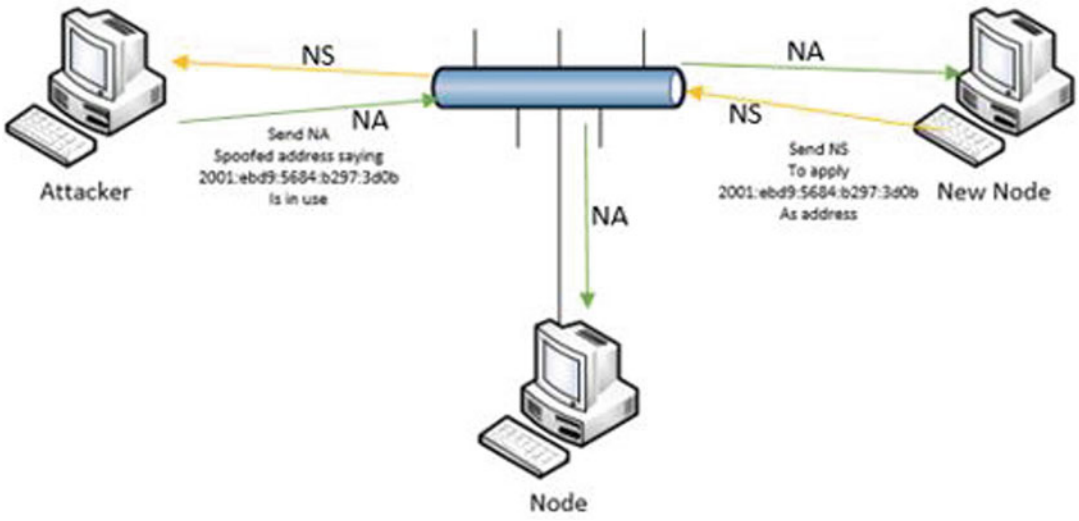
- Parameter spoofing: As mentioned earlier, Router Advertisement messages contain network parameter information, and they are very useful to the host to send IPv6 packets later. An attacker can send a Router Advertisement message (e.g., with a small hob limit), which contains false network parameters that can disturb the packet transmission and host's communications.

Neighbor Discovery Attack

Neighbor Solicitation and Neighbor Advertisement are two ICMPv6 messages that Neighbor Discovery Protocol (non-routing one) uses. Two of the most important jobs that NDP is responsible for are neighbor unreachability and Duplicate Address Detection (DAD). An attacker can use these functions as an advantage and launch an attack.

Duplicate address detection DoS attack: Another feature on IPv6 network is Duplicate Address Detection (DAD). When a node needs a new IPv6 address, it will send Neighbor Solicitation to all-nodes multicast address "FF02::1" to check whether that IP is in use or not. If the sender did not receive a reply, that means the IPv6 address is free and the new node can use it. An attacker can use this as an advantage and send a spoofed Neighbor Advertisement packet claiming that the address is in use every time that node sends a request. By using such an attack, the new nodes will not get an IPv6 address, and therefore there is not any connectivity (Fig. 5) (Zhao-Wen et al. 2007).

Neighbor Unreachability Detection failure: Neighbor Unreachability Detection (NUD) process detects when a neighbor is unreachable. Once this has happened, the node starts to send a Neighbor Solicitation packet to lost node address and waits for a Neighbor Advertisement reply for a short period. If no Neighbor Advertisement is received, the node will delete the peer node from its Neighbor Cache Entry table. An attacker can send a malicious Neighbor Advertisement reply to a Neighbor Solicitation request to show that the node is still alive and on the network which it is not.



IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games, Fig. 5 DAD attack

ICMPv6 Redirect Message Attack

IPv6 nodes use ICMPv6 "Redirect" message to find a better path to their destination. The router will send "Redirect" message to a node to optimize the packet routing process and the delivery path. The following attack types can utilize ICMPv6 redirect messages:

- The traffic can be forwarded to non-existent link.
- The traffic can be redirected to an existing node. This will result in the node being overwhelmed.

Gaming company has become more attractive targets for attackers during the last couple of years. Moving the gaming companies Internet Protocol from Version 4 to Version 6 will create some vulnerabilities which attackers can use to launch ICMPv6, DDoS, and some other malicious activities by bypassing the detection by using some of IPv6 new features such as Extension Headers and Fragmentations.

Attacking Tools

This section covers some of the most common attack tools to perform an attack on IP level.

Fragrouter is a network intrusion detection evasion toolkit developed by Dug Sing. It implements most of the attacks described in the Ptacek & Newsham in 1998. (It features a simple rule set language to delay, duplicate, drop, fragment, etc.).

THC-IPV6-ATTACK-TOOLKIT is a collection of attacking tools that can be used to test the implementation of IPv6 network and test firewall and NIDS. This collection contains the following tools (van Hauser 2008):

- parasite6: ICMPv6 neighbor solicitation/ advertisement spoofer, puts you as man-in-the middle, same as ARP mitm (and parasite)
- alive6: an effective alive scanning, which will detect all systems listening to this address
- dnsdict6: paralyzed DNS IPv6 dictionary brute forcer
- fake_router6: announce yourself as a router on the network, with the highest priority
- redir6: redirect traffic to you intelligently (man-in-the-middle) with a clever ICMPv6 redirect spoofer
- dos-new-ip6: detect new IPv6 devices and tell them that their chosen IP collides on the network (DOS)

Havij is an automated SQL injection tool that takes advantage of a vulnerable web application to find and exploit SQL injection vulnerabilities. An attacker can perform back-end database fingerprint, DBMS login names and password hashes, and much more like fetching data from a database. However, this tool is capable of accessing the underlying file system and executing the operating system shell commands.

Acunetix is a web vulnerability scanner designed to replicate a hacker's methodology to find vulnerabilities like SQL injection and DoS/DDOS attack. By using Acunetix you can use an extensive feature set of both automated and manual penetration testing tools, security analysis and repair detected threats.

Mendax is a TCP de-synchronizer that injects overlapping segments in randomly generated order. An attacker can use Mendax to evade NIDS. Mendax is not a router, but is a standalone TCP client program which can be used by an attacker to perform an evasion from an input text file, performs a fixed set of evasion technique, and sends restructured exploit to the victim host (Gorton and Champion 2003).

In Table 2 a summary of Evasion and Insertion attack tools is provided.

Related Work

Alnakhalny et al. (Saad et al. 2014) proposed a detection method for ICMPV6 flood attack based on Dynamic Evolving Neural Fuzzy Inference System (DENFIS). DENFIS is a system that uses online clustering to perform online and offline learning. The proposed system is based on self-machine learning. However, one important question here is if the attacker uses a mixture of method to bypass the detection, it will take time for the machine to learn that algorithm and detect future attack. Because of that, attackers will

IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games, Table 2 Evasion and Insertion attack tools

Tools name	Developer(s)	Evasion attack
Fragrouter	Dug sing	Most techniques described by Ptacek & Newsham
thc-ipv6	Van Hauser	Multiple attacking tools including DoS, DDoS, Evasion and Insertion attack
Havij	IT Sec team	SQL injection and web app evasion
Acunetix	Acunetix team	Web app analyser and evasion test attack
Mendax	Min G. Kang	TCP overlapping

change their method, and therefore the detection method could not be useful for such attack.

Anbar et al. (Saad et al. 2016) proposed An Intelligent ICMPv6 DDoS Flooding attack Detection Framework (v6IIDS) Using Backpropagation Neural Network. Their aim is to detect ICMPv6 Flooding attack using an Intelligent Intrusion Detection System in an IPv6 Network (v6IIDS). The proposed system detection has four processes. These processes are data collection and pre-processing, traffic analysis, anomaly-based detection, and ICMPv6 flooding detection.

Rafiee et al. (Rafiee and Meinel 2013) proposed a new algorithm to tackle the issue with Cryptographically Generated Addresses (CGA) [3972] and Privacy Extension [4941] in IPv6 state-less configuration. The proposed method uses a new way to generate Interface Identifier (IID) to reduce the computing cost and prevent security theatres related to state-less configuration such as IP spoofing. However, it seems the proposed algorithm cannot detect Duplicated Address Detection attack on IPv6.

Kent et al. (Kent and Seo 2005) provided Security Architecture for the Internet Protocol. In IPv6 unlike IPv4, Internet Protocol Security (IPSec) is mandatory. IPSec draws a line between protected and unprotected interfaces for host or network. If traffic want to cross the boundary, they are subject to the access control list that is specified by the system admin who is responsible for IPSec configuration. These controls indicate whether packets cross the boundary unimpeded, are afforded security services via AH or ESP, or are discarded.

IPSec provide an end-to-end security between end hosts and all intermediate nodes. IPsec has the following weaknesses (Yang et al. 2010; Arkko and Nikander 2005):

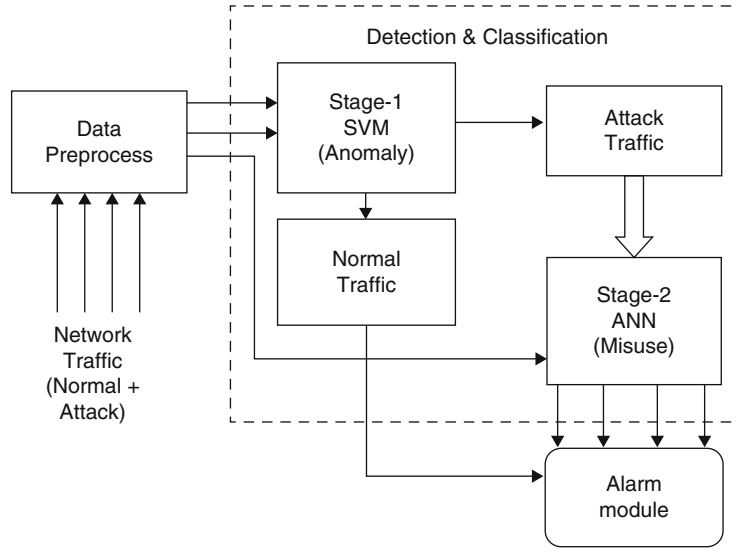
- Not support the upper layer
- Because it needs key exchange, it will use IKE management, which requires a valid IPv6 address. So it cannot work when a new host joins a network and therefore is not able to protect Network Discovery Protocol.

Because of the complex configuration, most of the users do not implement IPsec for link local addresses.

Kempf et al. (Kempf et al. 2005) proposed SEcure Neighbor Discovery (SEND) protocol to mitigate the issue of IPsec for link local commination. SEND is an extension of NDP that adds several options such as Cryptographically Generated Addresses (CGA), RSA Signature and Timestamp, and Nonce Options. In addition, they introduce four new Authorization Delegation Discovery, Certification Path Solicitation Message Format, Certification Path Advertisement Message Format, Router Authorization Certificate Profile and Suitability of Standard Identity Certificates (Kempf et al. 2005; Securing IPv6 2002).

A review of SEND done by Meinel et al. (Alsa'Deh and Meinel 2012). They are challenging SEND as it is not provided link layer security and cover NDP communication confidentiality. The Cryptographically Generated Addresses cannot assure the real node identity. Because of the structure of SEND, it will use more CPU of nodes and bandwidth to process. In addition, if Router Authorization and Standard Identity Certificates implement into routers, It will put an extra workload on them.

Hussain et al. (Hussain et al. 2016) proposed a two-stage hybrid classification (Fig. 6) method using Support Vector Machine (SVM) as anomaly detection in the first stage and Artificial Neural Network (ANN) as misuse detection in the



IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games, Fig. 6 Two-stage hybrid classification with SVM and ANN (Hussain et al. 2016)

second. The advantages of using SVM and ANN are better classification accuracy and a low probability of false positive. The proposed system classifies the type of attack into four classes: Denial of Service (DOS), Remote to Local (R2L), User to Root (U2R), and Probe. The first stage is looking for any abnormal activities that could be an intrusion, while the second stage does the future analysis, and if there are any known attacks, it will classify them into the four categories that were already mentioned.

Data Preprocess will prepare and pre-process network traffic in the data pre-process module. Once data has been received and pre-processed, it will be sent to the next process, which is "Detection and Classification." The detection and classification process has two stages: NIDS using SVM for anomaly and ANN for misuse detection. The data then passes to the Alarm module, which interprets event results on both stages and reports the intrusion detection activity.

Conclusion

IPv6 introduces new features and capabilities. These results in new issues, and security issues is one of the most important among them. Most of the vulnerabilities are common between IPv4 and IPv6, and because of the changes that were made in the IPv6 implantation, additional vulnerabilities arise as well. There are many features which are new and unique to IPv6. One of them is the improved support of headers (extensions and options) which were not existing before in IPv4.This entry reviewed an overview of Internet Protocol Version 6 (IPv6), IPv6 new features, and some of the most common vulnerabilities; also, a review was discussed for existing solutions and how those solutions can mitigate the vulnerability discussed in this entry. By adopting IPv6, gaming industries will become an attractive target for attackers to launch an attack such as ICMPv6 and DDoS to game companies. These sorts of attacks already launched to Sony, EA, and Steam really affected the gaming industry in terms of availability. In addition, the customer data on gaming companies could be in danger, as attackers could use IPv6 new features to bypass the detection on NIDSs and do malicious activities on gaming server.

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Islam

▶ Healthcare Robots with Islamic Practices

Islamic Calendar

► Healthcare Robots with Islamic Practices

Islamic Prayers

► Healthcare Robots with Islamic Practices

Itch.io, History of

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Synonyms

Publishing; Web Games

Definitions

Indie game: short for independent game, a game typically created by a small team of developers without the financial or labor backing of major production/publication studios.

Indie developer: short for independent developer studio, a team of game developers working without assistance from major production/publication studios.

Introduction

Itch.io is a web-based video game publishing platform built specifically for early indie/learning developers. Originally released in 2013 by *Leaf Corcoran*, the platform has become rapidly more popular among a niche community of developers within the wider gaming industry, as of the most recent public report (Hayes 2019) hosting over 200,000 games, with rough estimates that the platform likely hosts 250,000–300,000 games at the time of writing (October, 2020), based on community estimates on daily uploads. The platform gears itself toward new developers by an especially low barrier to enter publishing games, providing accessible access too and hosting game jams, providing development tools, and regularly publishing information on blogs that are geared toward starting indie developers.

History

Prior to its creation, the original concept for *Itch.io* was to create an online interface for making a customizable video game page where indie developers could quickly post their content online for the world to see. However, the service expanded both prior to, and in the early years of the website. These services continued to expand as the community of the site gained prominence within the indie development community.

By 2015, *Itch.io* has grown to a more dedicated and well-established indie development platform, with support for both participating in and hosting game jams, dedicated servers to dealing with issues, communities following developers, or indie groups on the site; at the time, they hosted over 15,000 games and applications, according to their released site statistics. Similarly, in early 2016, the official release of the *Itch App* created a desktop application interface for the previously solely web-based site.

From 2016 onward, a great effort to expand, polish, and enhance existing services and platforms can be seen, much of which can be seen by the enhancing of their desktop application and expansion of their community on their site, including additions in customization options for game pages and analytics for developer postings.

User Interaction

Users of *Itch.io* largely approach the platform from at least one of the following purposes:

The user is...

1. A developer looking to publish games
2. A developer looking for game development tools
3. A developer looking to participate in game jams
4. A gamer looking to play indie games
5. A company/group looking to host/sponsor a game jam

Most of the traffic of the site is geared toward the publication and purchasing/downloading of games, points 1 and 4, respectively. Though the game jam services are also an especially notable portion of the site (Vu and Bezemer 2020), and according to released *Itch.io* statistics, they attract a large portion of new users to the site. This has been especially true recently, with the top 5 game jams (2 from 2020, 2 from 2019, and 1 from 2018), accounting for a cumulative total of over 45,000 individuals/teams registering for the events and over 10,500 games added to the site.

Playing Games on Itch.io

Many games on *Itch.io* are entirely free to play or follow the "pay what you want" model of sales, though the platform does allow for developers to have a set costs for games. Additionally, with the added ability to play HTML5 games in their respective web browser, users do not even necessarily have to log in to play some of the games on the platform. However, for access to the vast majority of the library, a user will need to sign up for a free account and download a game from a given page.

A majority of games on the platform seem to be set to the "pay what you want" model, which a small portion of users regularly donating money to the developers of games they enjoy, and users are also given the ability follow and interact with developers on forums on the game's respective page or within the sites' social forum directly. Once a user has downloaded a game on itch.io, they permanently have access to that game and any new editions that come out of it, though it is not uncommon for developers of paid game projects to post a game's alpha, beta, demo, or any other marketing materials as a separate posting from the finalized product to avoid giving away their game for free.

Publishing Games on Itch.io

As *Itch.io*'s original conceptualization was based around the concept of game publishers, one can still see this reflected in the site's available publication and developer features. Posting a game on *Itch.io* is free, with no limitations on the quantity of products you can post or the quality of posting options. Customization for game and developer pages is built into the site, and a developer can, without opening any other application or knowing how to code, do the following:

- Post on forums
- Change the page stylizations
- Add or edit content of the game/developer page
- Add dev logs
- Change settings or pay models of the page
- View game analytics
- Get embeds for websites or social media
- Have a handful of other useful features

The number of available free features, and general pro-indie/new developer attitude of the community, has led to itch.io gaining many of its developers. Additionally, *Itch.io* regularly posts on forums and developer communities with indie developer strategies for designing, developing, publishing, and marketing new indie games.

Itch.io as a Political Institution

Itch.io, being an American company, has both officially and unofficially taken a number of political stances regarding political issues in the USA. The most notable of these events is the support the platform has given for the NAACP and the Black Lives Matters movement, where the platform raised over eight Million dollars in June of 2020 in response to the George Floyd Protests throughout the USA (Statt 2020). This money was raised

by creating a purchasable indie game bundle of games created by African American artists or that strongly featured socio political discussions of race and racial intolerance. This stance generated a small amount of political backlash from parts of the *Itch.io* community but was largely praised both within and without the *Itch.io* community and drew many artists to the site for the first time (Squirrelrampage 2020).

Itch.io and Steam

The expansion of the video game market, especially within the past decade after the economic recovery of the 2008 global recession, has seen a dramatic rise in digital publication platforms as one of, if not the most common, the ways for purchasing and obtaining video games, for both PC and console games. Its most notable competitor, and the largest market share for publication and distribution of digital games then, both indie and otherwise, is of course *Steam*, the publication platform owned by *Valve Corporation*.

Steam also hosts a very large indie community and has significantly greater universal brand recognition. However, *Steam* has a notably higher bar for the posting and sale of games, with developers needing to be formally recognized and signing legal paperwork before joining and paying $100 as a starting fee and then for each additional game they look to post on the platform. This has caused many developers to view itch as somewhat of a "starter platform" where they first go to develop their skills, before producing games that are profitable enough to then warrant the posting on *Steam* (Maiberg 2015).

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► Indie Game

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ITD

► User Acoustics with Head-Related Transfer Functions

Iterative Design

► User-Centered Design and Evaluation Methodology for Virtual Environments

Iterative Game Design

► Analog Prototyping for Digital Game Design

J

Japanese Chess

► Contemporary Computer Shogi

Justification

► 2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making

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K

K-12 Education

► Augmented Learning Experience for School Education

Kaizo

► Underground Design of Kaizo Games

Key Early Verticals: Challenges and Limitations in Implementation of Augmented Reality

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Synonyms

Augmented reality; Mixed reality; Virtual reality

Definitions

Augmented reality (AR) augments real world with virtualized contents (i.e., objects and/or supporting information) which appears to coexist in the same space as the real world (Palmarini et al. 2018). Its predecessor, i.e., virtual reality (VR), on the contrary, generates a completely artificial environment of the reality.

Key Early Verticals for Augmented Reality

Although the promising notions of AR and VR were coined several decades ago, the technologies enabling AR have just recently converged to a critical point enabling people to enjoy its experiences and to fully reap its benefits (Yuan 2017). AR is believed to be one of the key technology enablers for Industry 4.0 and is anticipated to disruptively change our world in many aspects. This section briefly depicts the key early verticals of AR in numerous industrial sectors, i.e., manufacturing, healthcare, logistics, design and architecture, military, and data centers (Syberfeldt and Gustavsso 2017; Chandler 2017) along with their salient characteristics.

Manufacturing: Connected devices and wearable products have rapidly penetrated across the manufacturing industry, hence opening new doors for innovative AR experiences. AR is currently making rapid strides in numerous areas. It is used

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for the monitoring and solving of pain points experienced on the shop floors, i.e., pain points along with key performance indicators (KPIs) could be directly projected to the engineers and maintenance teams in order to analyze and resolve the issues in real time. This is also efficient in case of production downtime due to a broken part of a machine, as teams equipped with AR capabilities can quickly respond to the hardware problems in almost no time. AR could further assist the production teams in the physical asset-based logistics and status of the physical stock on the shop floor, and the same can be superimposed in the form of digital content to augment the real-time views (Caricato et al. 2014; Uva et al. 2018; Chang et al. 2017).

Healthcare: Healthcare is one of the most dominant sectors impacted by AR in numerous ways, i.e., from training medical students about the human anatomy to counseling mothers struggling with breastfeeding by effectively allowing the counselors to *see through* the eyes of mothers via an AR wearable device, to assisting the patients to accurately describe their past and existing medical conditions to their doctors, to enabling nurses to locate human veins conveniently during intravenous injections, to facilitating the curious consumers of the pharmaceutical industry with the 3D views of drug actions and effects in the human body, to practicing minimally invasive surgeries by enabling the surgeons to *see through* the patient (without the need for opening them up) during the surgical planning and image-guided surgery, etc. (Herron 2016; Chen et al. 2017).

Logistics: One of the biggest waves of change anticipated in logistics industry is in the form of AR technology, i.e., in the warehouse operations, wherein, notion of *pick-by-vision* for providing a hands-free digital approach could be employed instead of a slow and error-prone *pick-by-paper* approach in order to optimize picking process (the software employed for *pick-by-vision* could have features like the barcode reading, indoor navigation, real-time object recognition, seamless integration with centralized warehouse management systems, etc.), in the warehouse planning to accommodate a number of value-added services by visualizing rearrangements by incorporating digital representations of envisaged future settings in the current warehouse environment, and in the freight transportation as loaders could have access to the real-time digital data about the next pallet to be loaded and its placement in the vehicle along with the pertinent loading instructions thus saving the tedious process of paper-based cargo lists and speeding up the freight loading process (Stoltz et al. 2017; Glockner et al. 2014).

Design and Architecture: Over the past few decades, one of the key challenges confronting designers was to dive deep into physical space of a structure or an object that they are conceiving. Traditionally, 3D objects were conceived over the 2D screens. However, as of late, more meaningful and lucrative ways have transpired and AR experiences undoubtedly lies at heart of the same, i.e., from the powerful 3D printing facilitating the companies and firms to rapidly transform their concepts into implementation thus ultimately leading to reduction in costs and securing of more clients to a collaborative design process for sourcing of innovative ideas, variants, and its feedbacks from the geographically distributed consumers during the product's planning stage, to equipping the architectural project teams and their clients to immerse in an interactive AR experience for monitoring progress of ongoing projects via a real-time digital modeling of a construction site, thus avoiding the tedious task of walking clients on the construction sites and preventing any unwanted accidents, to the spatial augmented reality revolutionizing the automotive industry by enabling the designers to assess curves and geometries more efficaciously by projecting virtual data on a real vehicle model during its development process (i.e., typical virtual data is often being displayed on monitors and its size is often scaled down and is not a precise reflection of the reality), etc. (Chi et al. 2013; Elia et al. 2016; Behzadan et al. 2015).

Military: AR has been making its stronghold in the battlefield, i.e., from projecting precise maps, navigation way points, friends or foe discrimination, and pertinent information to a soldier's field of vision, to integrating specialized AR gadgets to a weapon control system for

enhancing the mission's effectiveness, to training of the combat personnel for complex conditions arising in the battlefield through injecting of virtual threats into a realistic environment for ensuring that the troops are skilled enough to quickly respond and operate the equipment in every possible scenario, to training fighter pilots for diverse battle scenarios and certain specialized cockpit operations, i.e., aerial refueling and missile deployment, as most of their trainings are conducted over flight simulators and setting up live combat operations could be very expensive (You et al. 2018; Karlsson 2016).

Data Centers: AR is anticipated to bring tremendous benefits to data center planning and to a wide range of its operations and processes, i.e., from remote management of the data centers to spatial tours via the 3D real-time imaging superimposed with pertinent contextual information so as to have a better understanding of local prevailing circumstances, to the navigational guidance in a data center for better identification of error-prone devices or installation of a new device along with installation instructions, to the color labeling of identical-looking racks and cabinets within a datacenter to reflect status messages (i.e., notifications, alarms, or warnings) or operational analyses along with troubleshooting instructions if any, to the identification of a device and device-related specific virtual information and real-time datasets by employing the QR scanner and many more (Deffeyes 2011; Emeis et al. 2017).

Challenges and Limitations in Implementation of Augmented Reality

Despite a number of potential applications of AR in modern-day industries, there are still several challenges and limitations that hinders its true realization (Akayra and Akayra 2017; Zhang et al. 2017). Some of these challenges and limitations are discussed as follows.

Low Latency Monitoring and Tracking: In order to have an essential AR experience, it is indispensable to precisely track and subsequently monitor an individual's location, the objects and people surrounding him/her, and more interestingly, what actions are being carried out through their eyes, hands, and voice and all in few milliseconds so as to ensure that the precise contextual information gets layered on the actual environment via an AR device. Hence, the design of a state-of-the-art real sense cameras (possessing the full five-finger integration), diverse sensors, and microphones for an AR device still poses a daunting challenge yet to be fully realized.

Seamless Optical Displays: A seamless optical display blending (both) physical and digital world adds another layer of complexity in the early realization of AR. It is pertinent to note that VR is already utilizing high-resolution innovative screens, in whose production, the smartphone industry has been actively involved over the past few decades. In case of VR, the user typically glances on the screen; however, in AR, it is essential to look through the screen so as to still experience the real-world environment.

Computing Power: Power is one of the serious challenges currently being faced by the AR industry. Today, with the continuous evolution of stronger yet ever smallest processors, there would certainly be (in the near future) powerful enough processors specifically for AR. Thus, powerful processors require powerful batteries and especially with characteristics, i.e., low consumption, high capacity, and small enough to be compatible with lightweight AR wearable displays. Complexity versus implementation is an issue and balance is still to be determined.

Scaling: Interpreting (or rendering) of the digital data into meaningful graphics and subsequently scaling it down to suit the perspective of individual's visual field adds a significant challenge in the vast implementation of AR.

AR Software: One of the indispensable components of AR software is its competence to efficiently accumulate, process, and analyze potentially diverse range of inputs simultaneously and transform them accordingly based on new digital information so as to provide the high-end AR experiences. For realizing the same, high-speed connections would thus be required to tie the AR software to the back-end services, thus

ensuring the future AR-enabled devices to be the world's most capable Internet of Things (IoT) endpoints.

Conclusion

The notion of AR has grown by leaps and bounds over the past few decades, but very few of us know how far it has come in reality. At the time of writing of this article (2018), various tech giants such as *Google, Apple, Facebook*, etc., have launched their AR development kits and a new wave in technology has finally set in. Also, a number of industries have started embracing AR and specific applications are now being experienced in their initial forms. *But how big would the AR impact be?* In order to address this question, this article serves as a major reference for not only highlighting some of the key early verticals for AR in various industrial sectors but also deliberates on some of the critical challenges and limitations hindering its true realization. It is beyond any doubt that AR is soon going to be a mainstream product and either people would be wearing AR headsets for most of their time or AR would replace everything we do on smartphones, act as a new interface for laptops or desktops along with numerous specialized applications across all industrial sectors. This ultimately would lead to another revolutionary wave in the gaming industry too.

Cross-References

- History of Virtual Reality
- Mixed Reality
- Potential of Augmented Reality for Intelligent Transportation Systems

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King of Fighters, a Brief History

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Synonyms

Fighting game; Interactive game; Video games

Definition

SNK: A Japanese video game hardware and software company.

KoF: The King of Fighters is a series of fighting games by SNK.

Introduction

The King of Fighters (KoF) is a series that started in arcades on SNK's own game system. Starting in 1994, leading up to the advent of the greatly awaited King of Fighters XV – the 15th edition in 2021, this entry goes over the history of the series, SNK, spinoffs, and other media, as well as the e-Sports scene.

The Games and Their Unique Systems

Starting off, the main set of KoF games began with the King of Fighters '94 for the Neo Geo, which was followed with yearly releases up until 2003, where SNK started taking more time to make the new editions of the game series. KoF XI released in 2005, KoF XII alongside 2002 Unlimited Match in 2009, KoF XIII in 2010, and KoF XIV in 2016 (Mendoza 2020).

The King of Fighters series differentiates itself from its peers with its 3-on-3 team battle setup. Traditionally, fighting games ask players to select a single character to use against their opponent, but in the KoF series players select a team of three characters to challenge their opponent's three characters. After one of the characters is downed, the next character in line will tag in. Characters standing in the backlines can sometimes perform support attacks to help.

Along with previously discussed mechanics, KoF employs its own set of mechanics, such as the many jump options (short hop, short jump, hyper hop, hyper jump, etc.) as well as the MAX Mode which could open up Death Combos in certain iterations. King of Fighters has no predetermined combos, and players have to make up their own using basic, unique, and special moves.

Spinoffs and Other Media

The King of Fighters have inspired spin-off titles such as the Maximum Impact series, which offered KoF in a 3D environment in 2004 (Maximum Impact), 2006 (Maximum Impact 2), and 2007 (Maximum Impact Regulation-A). Other spin-off titles include The King of Fighters '94 Re-Bout (2004), The King of Fighters Neowave (2004), The King of Fighters XI (2005), The King of

Fighters '98 Ultimate Match (2008), and The King of Fighters 2002 Unlimited Match (2009).

There are also a ton of manga for the main series from 1994 to 2000, and more recently, one for XIV. For example, *The King of Fighters: A New Beginning* is a Japanese shōnen manga authored by Kyōtarō Azuma as an adaptation of SNK's 2016 fighting game The King of Fighters XIV. There are also quite a few drama CDs as well as some animations. One of those animations is a complete retelling of KoF '94, called *The King of Fighters: Destiny*. There was also a movie adaptation *The King of Fighters* in 2010 starring Sean Faris as Kyo Kusanagi, Maggie Q as Mai Shiranui, Will Yun Lee as Iori Yagami, and Ray Park as Rugal Bernstein. However, it was none too faithful to the source material and was panned by critics and audiences alike (*The King of Fighters*).

SNK Company Turmoil

After the release of KoF 2000, SNK filed for bankruptcy in 2001 and auctioned the intellectual property rights for its franchises. This led to KoF 2001 and the original 2002 being created by a different company, called Eolith. SNK's founder and other executives founded a new company under the name Playmore later in August of 2001. In late October of the same year, Playmore had successfully reacquired the SNK intellectual property rights and began rehiring former employees.

Esports Scene

Several editions of The King of Fighters appeared in e-sports competitions. Some tournaments have used KoF '95 through '98 Ultimate Match (some as recent as 2020). Before the release of KoF XIV, the e-sports tournaments mainly featured 2002 Ultimate Match and KoF XIII. A particularly outstanding finale for one of the KoF XIII tournaments at EVO 2013 involved a 2-0 comeback followed by a reverse 3-0. However, the lack of documented e-sports tournaments for The King of Fighters makes it difficult to expound on the KoF e-sports scene.

Conclusion

The King of Fighters is a fighting game series that has existed for 27 years as of 2021, and that has survived through the bankruptcy of its game publisher SNK. Over the years, the game has run on many platforms including Neo Geo arcade, Atomiswave arcade, Taito Type X arcade, Sega Saturn, Dreamcast, PlayStation, Game Boy, Wii, Nintendo Switch, iOS, Android, Microsoft Windows, and Xbox. King of Fighters differentiates itself using its unique 3-on-3 combat and many ways to execute attacks to such a degree that it has received widespread appeal.

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Kingdom Hearts (2002): An Analysis

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Synonyms

Action role-playing game; Hack-n-slash

Definitions

Action role-playing game	It is a specific type of role-playing game where the player controls a character engaged in real-time combat.
Hack-n-slash	A type of combat that focuses on quick, hand-to-hand or melee weapon combat.

Kingdom Hearts (2002)

Kingdom Hearts is a single-player, action role-playing game that is a crossover between two companies and their universes. These two companies consisted of Square Enix (originally known as just Square) and Disney Interactive. Square Enix and Disney Interactive Studios were the major developers and publishers, but the series itself has also had help from other companies to compile the game together. Kingdom Hearts resides within its own series (Kingdom Hearts) and spans over nine main games. Kingdom Hearts was first created on its own in-house engine, Luminous Engine, but with the release of Kingdom Hearts 3, the game will be switching over to Unreal Engine 4. Kingdom Hearts was a PlayStation 2 exclusive, released on March 28, 2002. The player takes on the role of the main protagonist, Sora. Kingdom Hearts is rated as E, but as the series progressed, the ESRB rating has change to E 10+ (Entertainment Software Ratings Board).

Kingdom Hearts follows the story of a boy, Sora, who sets off on an adventure after his home, Destiny Islands, is consumed by Darkness. Throughout the series of the games the player gets to watch Sora grow as a hero. In the original game he arrives in Traverse Town and meets a new set of friends, Donald and Goofy, and then sets off to find Riku, Kairi, and King Mickey. His relationship with every friend he meets enables his growth to flourish throughout the story. The trio meets many heroes and villains spanning across both the Disney and Final Fantasy universes. Since Kingdom Hearts consists of both Disney and Square Enix characters, they wanted to attract both hardcore and casual players. They were able to create a game that could bring together people from all ages, young or old, to enjoy this series of games. Kingdom Hearts managed to secure the spot for the 10th best-selling PlayStation 2 game of all time as well (Game Enthusiast).

Kingdom Hearts took much influence from Square's Final Fantasy franchise, and it consists of a hack-n-slash approach to its gameplay. The main objective was to travel around defeating bosses to advance to different worlds. The player controls Sora with the ability to use basic attacks, special attacks, magic, and in some cases, dodges. Meanwhile, Donald, Goofy, and/or another character who can replace the two will assist Sora within battles. The player can also control the behavior of the assisting characters to a certain extent. Sora's stats are based around his level, and the game in its entirety is set around an experience point system. Defeating enemies is the only way to earn experience points which in turn increases Sora's level (capping at 100). Kingdom Hearts is relatively linear; the player moves from world to world defeating Heartless, bosses, etc., but the player also has the chance to run into short side-quests to secure items, experience, etc. Among all these systems set in place, the combat interface seems to be the simplest. There is a command bar consisting of Attack, Magic, Items, and Specials. Lastly, there is a health bar and magic bar, as well as both of the assisting character's health and magic bars.

Kingdom Hearts was a one of kind collaboration, which was perceived rather impactfully in the public's eyes. Due to its massive success, Kingdom Hearts never had any controversies surrounding the series. At first, no one thought Disney and Final Fantasy would be a good combination but were proven wrong. The original characters, especially Sora, were unique because the player could witness how their personalities grew and altered throughout the stories of each of the nine games. Kingdom Hearts made the 21st

spot on IGN's top 25 PS2 games of all time. IGN had this to say, "The premise behind the game was completely absurd: Disney cartoon characters like Mickey Mouse thrown in with Square Enix characters to make a new kind of action RPG. However, as strange as it sounds, these two dissimilar franchises came together incredibly well" (IGN). The characters – original, Disney, and Final Fantasy – helped develop the game into such a hit as it is still today. Kingdom Hearts suffers from linear progression but not in an unplayable manner. Kingdom Hearts has not really changed up its graphical capabilities over the years, but here is a YouTube video showcasing the evolution of the series: https://www.youtube.com/watch?v=Wu-QQgWeCi4.

As stated earlier, Kingdom Hearts managed to secure the spot for the 10th best-selling PlayStation 2 game of all time as well (Game Enthusiast). Kingdom Hearts had such a unique way of going about its gameplay, but it could be comparable to games like the "Tales of" series, the "Persona" series, and of course the "Final Fantasy" series.

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Knowledge

▶ World Representation in Artificial Intelligence

Knowledge Representation and Reasoning

▶ World Representation in Artificial Intelligence

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Lattice Boltzmann Method for Diffusion-Reaction Problems

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Synonyms

Cellular automata; Diffusion-reaction problems; LBM; Numerical methods

Definitions

- Cellular automata
  A mathematical model based on simple and local rules capable of generating complex behaviors.
- LBM
  Lattice Boltzmann method, a numerical method based on kinetic equations formulated on a mesoscopic scale.
- LGCA
  Lattice gas cellular automata, a specific cellular automaton, whose proposal is to simulate fluids using simple and local rules that imitate a particle dynamics.

Introduction

The lattice Boltzmann method (LBM) is based on the fundamental idea of constructing simplified kinetic models that incorporate the essential physics of the microscopic processes, so that the estimated properties satisfy the macroscopic equations. LBM is especially useful for modeling complex boundary conditions and multiphase interfaces (Chen and Doolen 1998). Extensions of this method are described in the literature, including simulations of turbulent fluids, suspended fluids, and diffusion-reaction systems (Wei et al. 2004).

Lattice-based models have some advantages compared to the traditional numerical methods (Rothman and Zaleski 1994). The simulation occurs in a regular lattice and can be efficiently implemented in a massively parallel computer. Solid boundaries and multiple fluids can be introduced in a simple way, and the simulation is done efficiently, regardless of the complexity of boundary or the interface (Buick et al. 1998). In the case of lattice gas cellular automata (LGCA), there are no numerical stability problems because their evolution follows integer arithmetic. For LBM, accuracy and numerical stability depend on the Mach number, which is the ratio of maximum speed to the speed of sound. The computational cost of the LGCAs is lower than the cost of LBM methods.

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However, the system parameterization (e.g., viscosity) is difficult to do in LGCA models, and the dynamics obtained is less realistic than for the LBM.

This article will demonstrate how to use the advantages of lattice Boltzmann method to solve diffusion-reaction problems.

Theoretical Foundations

Diffusion is an example of a matter transport phenomenon where the particles of a set move randomly and spread in the medium containing them. For example, we can smell perfume because it diffuses into the air and makes its way into our nose. From macroscopic point of view, these movements cause the set to move from the higher-concentration zones to the low-concentration zones. Diffusion-reaction equations arise naturally in systems consisting of many interacting components, like chemical reactions, and are widely used to describe pattern formation phenomena in a variety of biological, chemical, and physical systems.

The diffusion equation is given by

$$\frac{\partial \phi}{\partial t} = \alpha \frac{\partial^2 \phi}{\partial \mathbf{x}^2} + F, \tag{1}$$

where $\alpha(\mathbf{x}) > 0$ is the diffusion coefficient in $\mathbf{x}$, $\boldsymbol{\phi}(\mathbf{x},t)$ is the amount that is being diffused, and $F(\phi,\mathbf{x},t)$ is a portion of internal contribution (source term). The portion on the left is time variation, and the first portion on the right is spatial variation.

Finite Difference Approximation

The following analysis was performed by Mohamad (Mohamad 2011), for a one-dimensional problem; however, the extension for two-dimensional and three-dimensional problems is analogous. Moreover, the analysis takes into account diffusion Eq. (1) without the source term. A finite difference method will be used in the temporal term, and central differences in the spatial term, giving us the following approximation of the diffusion equation in a given node i:

$$\frac{T_i^{n+1} - T_i^n}{\Delta t} = \alpha \frac{T_{i+1}^n - 2T_i^n + T_{i-1}^n}{\Delta x^2}, \tag{2}$$

where T_i^n corresponds to the amount that is being diffused at node i at time step n, Δt is the discrete time step, and Δx is the discrete spatial step.

Isolating the term of interest from Eq. (2), we have

$$T_i^{n+1} = T_i^n + \frac{\alpha \Delta t}{\Delta x^2}\left(T_{i+1}^n - 2T_i^n + T_{i-1}^n\right). \tag{3}$$

Equation (3) can be rearranged as follows:

$$T_i^{n+1} = T_i^n\left(1 - \frac{2\alpha\Delta t}{\Delta x^2}\right) + \frac{2\alpha\Delta t}{\Delta x^2} \times \left(\frac{T_{i+1}^n + T_{i-1}^n}{2}\right). \tag{4}$$

Defining

$$\tau = \frac{2\alpha \Delta t}{\Delta x^2},$$

we have then

$$T_i^{n+1} = T_i^n(1-\tau) + \tau\left(0.5T_{i+1}^n + 0.5T_{i-1}^n\right). \tag{5}$$

The finite difference approximation steps were performed in a way that could be compared to the LBM methodology. Following the considerations of Mohamad (2011), the last term in Eq. (5) is an average of the quantity around T_i or, in other words, represents an equilibrium term of T_i. In this way, Eq. (5) can be rewritten as follows:

$$T_i^{n+1} = T_i^n(1-\tau) + \tau T_i^{eq}, \tag{6}$$

where T_i^{eq} is the equilibrium term of T_i.

Formulation of the LBM for Diffusion

The LBM is a numerical method whose equations are formulated on a mesoscopic scale. This

method is able to simulate the dynamics of fluids on a macroscopic scale (Chen and Doolen 1998). In the LBM, the fluid is represented by a set of particles which reside in a regular lattice with certain properties of symmetry. The dynamics that governs the simulation involves steps of collision and scattering of these particles through the lattice directions, following simple rules that satisfy the laws of conservation of mass (number of particles) and momentum. The macroscopic behavior of the fluid is obtained through statistical results on the data at the microscale. This section shows the formulation of the LBM for solving diffusion problems.

The kinetic equation for the distribution function $f_i(\mathbf{x},t)$ can be written as follows (Mohamad 2011):

$$\frac{\partial f_i(\mathbf{x},t)}{\partial t} + c_i \frac{\partial f_i(\mathbf{x},t)}{\partial \mathbf{x}} = \Omega_i \tag{7}$$

where i varies among the possibilities of direction for each cell, depending on the dimension of the problem. Among the available models, those that represent the Navier-Stokes equations are called $DnQb$ (where n refers to the dimension and b the number of lattice directions), proposed by Quian et al. (1992). For example, a 1D problem has one dimension and two lattice directions, so the model is called $D1Q2$. However, for 2D problems, the most common model used is $D2Q9$, which takes into account the diagonal directions.

The term on the left in Eq. (7) represents the scattering process, where the distribution functions evolve along the lattice directions with velocity $c_i = \Delta x/\Delta t$. The term on the right represents the rate of change of the distribution function in the collision process. According to Chopard et al. (2002), the most natural way to define the collision term is by averaging the micro-dynamics and factoring it into a product of average quantities. However, for more sophisticated fluids, the collision term requires a large number of floating point operations at each node of the lattice at each instant of time, which would increase the computational cost. One solution is to use the BGK approximation, which uses a relaxation term toward the local equilibrium (Bhatnagar et al. 1954).

The collision operator can be represented by the BGK approximation:

$$\Omega_i = -\frac{1}{\omega}\left[f_i(\mathbf{x},t) - f_i^{eq}(\mathbf{x},t)\right], \tag{8}$$

where ω represents a temporal relaxation on the equilibrium distribution function, related to the diffusion coefficient on the macroscopic scale.

Equation (7) with the BGK approximation can be discretized as follows:

$$\begin{aligned}&\frac{f_i(\mathbf{x},t+\Delta t) - f_i(\mathbf{x},t)}{\Delta t} \\ &\quad + c_i \frac{f_i(\mathbf{x}+\Delta x, t+\Delta t) - f_i(\mathbf{x},t+\Delta t)}{\Delta x} \\ &\quad = -\frac{1}{\omega}\left[f_i(\mathbf{x},t) - f_i^{eq}(\mathbf{x},t)\right].\end{aligned} \tag{9}$$

Replacing $\Delta x = c_i \Delta t$, we simplify to

$$\begin{aligned}&f_i(x+\Delta x, t+\Delta t) - f_i(\mathbf{x},t) \\ &\quad = -\frac{\Delta t}{\omega}\left[f_i(\mathbf{x},t) - f_i^{eq}(\mathbf{x},t)\right].\end{aligned} \tag{10}$$

What leads us to

$$\begin{aligned}f_i(\mathbf{x}+\Delta x, t+\Delta t) = f_i(\mathbf{x},t)[1-\tau] \\ + \tau f_i^{eq}(\mathbf{x},t),\end{aligned} \tag{11}$$

where $\tau = \Delta t/\omega$ is called temporal relaxation.

The dependent variable ϕ in reaction-diffusion Eq. (1) is related to the distribution function as follows (for $D2Q9$ model):

$$\phi(\mathbf{x},t) = \sum_{i=0}^{8} f_i(\mathbf{x},t). \tag{12}$$

The relationship between the diffusion coefficient α and the temporal relaxation term τ can be deduced by a multi-scale expansion (Mohamad 2011), providing

$$\alpha = \frac{\Delta x^2}{\Delta t D}\left(\frac{1}{\tau} - \frac{1}{2}\right), \tag{13}$$

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where D corresponds to the dimension of the problem.

For diffusion problems, assume constant the equilibrium distribution functions, not having macroscopic velocity action:

$$f_i^{eq} = A_i. \tag{14}$$

The equilibrium distribution function must satisfy mass conservation and momentum:

$$\sum_{i=0}^{8} f_i^{eq} = \Theta \tag{15}$$

and

$$\sum_{i=0}^{8} f_i^{eq} c_i = 0. \tag{16}$$

In general, $A_i = w_i\Theta$, which implies $f_i^{eq} = w_i\Theta$. The equilibrium distribution function for the diffusion problem can be chosen as follows (Mohamad 2011):

$$f_i^{eq} = w_i\phi(\mathbf{x}, t), \tag{17}$$

with ϕ given by Eq. (12) and w_i are weight factors relative to each direction of movement. The factors w_i shall meet the following criteria:

$$\sum_{i=0}^{8} w_i = 1. \tag{18}$$

In this way, the equilibrium distribution functions can be summed in all directions, providing

$$\sum_{i=0}^{8} f_i^{eq}(\mathbf{x}, t) = \sum_{i=0}^{8} w_i\phi(\mathbf{x}, t) = \phi(\mathbf{x}, t). \tag{19}$$

LBM Diffusion-Reaction to Vector Field

So far we have shown the general formulation of the LBM for diffusion problems. In this section, we will apply this formulation to the problem of diffusion-reaction in vector fields. The reaction term can be treated as a source term in the LBM formulation. Thus, the LBM formula for reaction-diffusion problems is given by (Mohamad 2011)

$$\begin{aligned}\mathbf{f}_i(\mathbf{x} + \Delta\mathbf{x}, t + \Delta t) = {} & \mathbf{f}_i(\mathbf{x}, t)[1 - \tau] \\ & + \tau\mathbf{f}_i^{eq}(\mathbf{x}, t) \\ & + \Delta t w_i \mathbf{R},\end{aligned} \tag{20}$$

where $\mathbf{R}$ is the reaction term. In the formulation, $\mathbf{f}_i$ corresponds to the quantity being diffused. In this case, we want to apply the diffusion in a two-dimensional vector field: $\mathbf{f}_i(\mathbf{x}, t) = \left(f_i^u(\mathbf{x}, t), f_i^v(\mathbf{x}, t)\right)$.

In practical terms, this implies a duplicate structure, that is, we will now have a lattice for the component x and a lattice for the component y, and apply the LBM separately as follows:

$$\begin{aligned}f_i^u(\mathbf{x} + \Delta\mathbf{x}, t + \Delta t) = {} & f_i^u(\mathbf{x}, t)[1 - \tau] \\ & + \tau f_i^{u,eq}(\mathbf{x}, t) \\ & + \Delta t w_i R_u,\end{aligned} \tag{21}$$

$$\begin{aligned}f_i^v(\mathbf{x} + \Delta\mathbf{x}, t + \Delta t) = {} & f_i^v(\mathbf{x}, t)[1 - \tau] \\ & + \tau f_i^{v,eq}(\mathbf{x}, t) \\ & + \Delta t w_i R_v.\end{aligned} \tag{22}$$

The reaction term will be treated as the source term in the LBM (Mohamad 2011). In this way, the dynamics in (20) is rewritten as follows:

$$\begin{aligned}\mathbf{f}_i(\mathbf{x} + \Delta\mathbf{x}, t + \Delta t) = {} & \mathbf{f}_i(\mathbf{x}, t)[1 - \tau] \\ & + \tau\mathbf{f}_i^{eq}(\mathbf{x}, t) + \Delta t R_i,\end{aligned} \tag{23}$$

where:

$$R_i = \frac{w_i \mathbf{R} \cdot \mathbf{c}_i}{c_s^2}, \tag{24}$$

where $c_s = 1/\sqrt{3}$ is called speed of sound and w_i are weighting factors related to each of the i's directions.

The temporal relaxation parameter τ is related to the diffusion coefficient through Eq. (13). Finally, the equilibrium distribution will then be given by

$$f_i^{u,eq} = w_i u(\mathbf{x}, t), \tag{25}$$

$$f_i^{v,eq} = w_i v(\mathbf{x}, t), \tag{26}$$

where:

$$u(\mathbf{x}, t) = \sum_{i=0}^{8} f_i^u(\mathbf{x}, t), \tag{27}$$

$$v(\mathbf{x}, t) = \sum_{i=0}^{8} f_i^v(\mathbf{x}, t). \tag{28}$$

Cross-References

- ▶ Fluid Simulation
- ▶ Cellular Automata Methods
- ▶ Lattice Gas Cellular Automata for Fluid Simulation
- ▶ Lattice Boltzmann Method for Fluid Simulation

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Lattice Boltzmann Method for Fluid Simulation

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Synonyms

Cellular automata; Fluid simulation; LBM; Numerical methods

Definitions

- **Cellular Automata**
  A mathematical model based on simple and local rules capable of generating complex behaviors.
- **LBM**
  Lattice Boltzmann method, a numerical method based in kinetic equations formulated on a mesoscopic scale.
- **LGCA**
  Lattice gas cellular automata, a specific cellular automaton, whose proposal is to simulate fluids using simple and local rules that imitate a particle dynamics.

Introduction

The lattice Boltzmann method is a numerical method based in kinetic equations formulated on a mesoscopic scale, which simulates fluid dynamics on a macroscopic scale (Chen and Doolen 1998). In the last years, LBM has drawn the attention of the scientific community due to its ease of implementation and computational efficiency. Specifically in fluid dynamics, LBM has been used due to its ease of boundary conditions implementations (Chopard et al. 2002).

The method originated from the lattice gas cellular automata (LGCA) that, despite its advantages, is limited by its discrete nature: the

appearance of artifacts in the characteristic directions of the lattice and little flexibility to adjust physical parameters and initial conditions (Adilson Vicente Xavier 2006; Chen and Doolen 1998). It was later demonstrated that the dynamics of the LBM can be derived through the Boltzmann equation (He and Luo 1997a; Philippi et al. 2006).

Cellular automata is a mathematical model based on simple and local rules capable of generating complex behaviors. It was originally introduced by John von Neumann, under the name of cellular spaces, as an idealization of biological systems, with the particular goal to model systems capable of self-reproduction (Wolfram 1994). The LGCA is a specific cellular automaton, whose proposal is to simulate fluids using simple and local rules that imitate a particle dynamics. The essential characteristics of the microscopic interactions that are taken into account are the laws of conservation of linear momentum and conservation of the number of particles (Chopard and Droz 1998).

The LBM was introduced by McNamara and Zanetti (1988), where the authors show the advantage of extending the Boolean dynamic of cellular automaton to work directly with floating point numbers representing probabilities of particle presence.

Theoretical Foundations

The LGCAs are cellular automata that simulate fluids through simple models. In the LGCA, the fluid is represented by a set of particles which reside in a regular lattice with certain properties of symmetry. The dynamics that governs the simulation involves steps of collision and scattering of these particles through the lattice directions, following simple rules that satisfy the laws of conservation of mass (number of particles) and momentum. The macroscopic behavior of the fluid is obtained through statistical results on the data at the microscale.

The dynamics of microparticles in the LGCA model is described by the equation given below (Daniel Reis Golbert 2009):

$$n_i(\mathbf{x} + \mathbf{c}_i, t + \delta r) = n_i(\mathbf{x}, t) + \Delta_i(n(\mathbf{x}, t)), \quad (1)$$

where $n_i(\mathbf{x}, t)$ can assume the values 0 or 1 representing the absence or presence of particle moving from the cell in the position $\mathbf{x}$ to the neighboring cell $\mathbf{x} + \mathbf{c}_i$ at time step t ($\mathbf{c}_i$ are the directions of movement). The function Δ_i is a collision operator representing the influence of particle collisions. The index i represents the z possible directions of movement of the lattice, that is, $i = 1, \ldots z$.

Conditions of mass conservation and moment conservation are imposed on the collision operator, respectively, given by:

$$\sum_i \Delta_i(\mathbf{n}) = 0 \quad \text{and} \quad \sum_i \mathbf{c}_i \Delta_i(\mathbf{n}) = 0. \quad (2)$$

The physical quantities of interest are the macroscopic quantities, such as the specific mass and linear momentum at a point in the system (Chopard and Droz 1998). The distribution which corresponds to the probability of having a particle in the node $\mathbf{x}$, at time step t is defined as (Chopard et al. 2002):

$$N_i(\mathbf{x}, t) = \langle n_i(\mathbf{x}, t) \rangle, \quad i = 1, \ldots, z. \quad (3)$$

Following the usual definition of statistical mechanics (Chopard and Droz 1998), the local density of particles is the sum of the probabilities of the microscopic variables of occupation (Expression 3):

$$\rho(\mathbf{x}, t) = \sum_{i=1}^{z} N_i(\mathbf{x}, t). \quad (4)$$

Similarly, the linear momentum ($\rho\mathbf{u}$) is given by Chopard and Droz (1998):

$$\rho(\mathbf{x}, t)\mathbf{u}(\mathbf{x}, t) = \sum_{i=1}^{z} \mathbf{v}_i N_i(\mathbf{x}, t), \quad (5)$$

where $\mathbf{v}_i$ are the speeds related to each direction of movement. The time step is defined as δ_t and the displacement between the nodes of the lattice as δ_x. Thus, the six possible velocities $\mathbf{v}_i$ of the

particles are related to their directions of motion by:

$$\mathbf{v}_i = \frac{\delta_x}{\delta_t}\mathbf{c}_i. \quad (6)$$

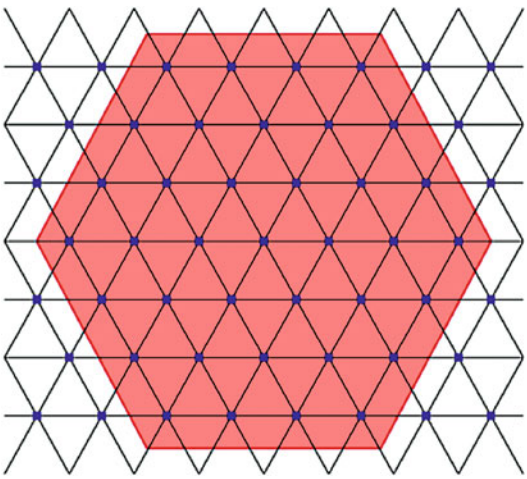
From LGCA to LBM Dynamics

The dynamics of the LGCA method are related to quantities present on the microscale. In the case of LBM, this dynamics occurs in the mesoscale (particle distributions), where the individual movements of each particle are not visible. In the mesoscale we will work with averages taken on regions of the lattice, so that these averages vary smoothly in both space and time (Guo and Shu 2013). Thus, we will use the (3) distribution covering an area of the lattice, rather than just a node. The N_i value will represent mean values of the distribution of microparticles described by the Boolean variables n_i over a region of the lattice, as shown in Fig. 1 (Daniel Reis Golbert 2009).

Applying the calculation of the averages on the LGCA equation of motion (1) we will arrive at the equation:

$$N_i(\mathbf{x} + \mathbf{c}_i\Delta x, t + \Delta t) = N_i(\mathbf{x}, t) + \langle \Delta_i(\mathbf{n}) \rangle, \quad (7)$$

where Δx represents the new spacing and Δt the new step of time considered in the mesoscale.



Lattice Boltzmann Method for Fluid Simulation, Fig. 1 Representation of a region of the hexagonal lattice

The collision term can be simplified by considering that the particles motion is not correlated before the collision step (principle of molecular chaos). Thus, the collision operator can be applied directly to the quantity representing the mean of the distribution of microparticles in the region of the lattice:

$$N_i(\mathbf{x} + \mathbf{c}_i\Delta x, t + \Delta t) - N_i(\mathbf{x}, t) = \Delta_i(\mathbf{N}). \quad (8)$$

Thus, we arrive at an equation similar to the lattice Boltzmann equation in the mesoscale, defined as (Daniel Reis Golbert 2009):

$$f_i(\mathbf{x} + \mathbf{c}_i\Delta x, t + \Delta t) - f_i(\mathbf{x}, t) = \Omega_i(\mathbf{f}(\mathbf{x}, t)), \quad i = 1, \ldots, z, \quad (9)$$

where f_i is called the particle distribution function (which assumes floating point values) and Ω_i the collision operator.

The macroscopic quantities of interest are calculated analogously to the process given in the LGCA (Eqs. (4) and (5)), where the density of particles is given by:

$$\rho(\mathbf{x}, t) = \sum_{i=1}^{z} f_i(\mathbf{x}, t), \quad (10)$$

and the linear momentum ($\rho\mathbf{u}$) is given by:

$$\rho(\mathbf{x}, t)\mathbf{u}(\mathbf{x}, t) = \sum_{i=1}^{z} \mathbf{c}_i f_i(\mathbf{x}, t). \quad (11)$$

BGK Approximation

The LBM is a numerical method whose equations are formulated on a mesoscopic scale, although it is able to simulate the dynamics of fluids on a macroscopic scale (Chen and Doolen 1998). The dynamics of this method is governed by the lattice Boltzmann Eq. (9).

According to (Chopard et al. 2002), the most natural way to define the collision term is by averaging the micro-dynamics and factoring it into a product of average quantities. However, for more sophisticated fluids, the collision term requires a large number of floating point

operations at each node of the lattice at each instant of time, which would increase the computational cost. One solution is to use the BGK approximation.

The BGK approach for the collision operator uses a relaxation term toward the local equilibrium (Bhatnagar et al. 1954). Thus, the collision operator through the BGK approximation is given by:

$$\Omega_i(\mathbf{f}(\mathbf{x},t)) = -\frac{1}{\tau}\left(f_i(\mathbf{x},t) - f_i^{\mathrm{eq}}(\mathbf{x},t)\right), \quad (12)$$

where τ is the relaxation term, which is related to the diffusive phenomena in the problem (viscosity of the fluid), and f_i^{eq} is the local equilibrium distribution function, which can be given by Eq. (14) forward. Thus, the lattice Boltzmann equation with BGK approximation is given by:

$$f_i(\mathbf{x}+\mathbf{c}_i\Delta x, t+\Delta t) - f_i(\mathbf{x},t) = -\frac{1}{\tau}\left(f_i(\mathbf{x},t) - f_i^{\mathrm{eq}}(\mathbf{x},t)\right). \quad (13)$$

In this model called lattice BGK (LBGK), the local equilibrium distribution was chosen so that the Navier-Stokes equations can be recovered asymptotically (Chen and Doolen 1998). The general form of this equilibrium distribution is given by Chopard and Droz (1998), Guo and Shu (2013):

$$f_i^{\mathrm{eq}}(\mathbf{x},t) = \rho\omega_i\left[A + B\frac{(\mathbf{c}_i\cdot\mathbf{u})}{c_s^2} + C\frac{(\mathbf{c}_i\cdot\mathbf{u})^2}{2c_s^4} + D\frac{(\mathbf{u}\cdot\mathbf{u})}{2c_s^2}\right], \quad (14)$$

where ω_i are weight factors related to the directions of the lattice, $\boldsymbol{\rho}$ and $\mathbf{u}$ are the macroscopic quantities of particle density and velocity (given, respectively, by Eqs. (10) and (11)), c_s is called the sound velocity, and A, B, C, and D are constant, whose values depend on the model used. These constants of the equilibrium distribution are related to the symmetry imposed on the mesh models used, which are necessary to recover the Navier-Stokes Equations (Daniel Reis Golbert 2009).

The LBGK models are the most used among the LBM models for fluid simulation. Among the available models, those that represent the Navier-Stokes equations are called *DnQb* (where *n* refers to the dimension and *b* the number of lattice directions), proposed by Quian et al. (1992), whose parameter values are shown in Table 1.

Incompressible Equilibrium Distribution Function

Applying a Chapman-Enskog multiscale asymptotic expansion in the lattice Boltzmann equation and assuming that the velocity of the fluid is less than the velocity of sound, it can be shown that it is possible to derive the incompressible Navier-Stokes Equations (Chopard et al. 2002). Therefore, it is necessary to use an incompressible equilibrium distribution function, which reduces the inherent compressibility effects of the LBM.

Lattice Boltzmann Method for Fluid Simulation, Table 1 Parameters of some models *DnQb*

Model	Direction vector $\mathbf{c}_i$	Weights ω_i	c_s^2
D1Q3	0, ±1	2/3, 1/6	1/3
D1Q5	0, ±1, ±2	6/12, 2/12, 1/12	1
D2Q7	(0,0), (±l/2,±$\sqrt{3}$/2)	1/2, 1/12	1/4
D2Q9	(0,0), (±1,0),(0,±1), (±1,±1)	4/9, 1/9, 1/36	1/3
D3Q15	(0,0,0), (±1,0,0),(0,±1,0), (0,0,±1), (±1,±1,±1)	2/9, 1/9, 1/72	1/3
D3Q19	(0,0,0), (±1,0,0),(0,±1,0), (0,0,±1), (±1,±1,0),(±1,0,±1), (0,±1,±1)	1/3, 1/18, 1/36	1/3

In an incompressible fluid, the density is approximately constant (denoted by ρ_0) and its fluctuation (denoted by $\delta\rho$) must be of the order $O(M^2)(M \to 0)$, where $M = \mid \mathbf{u} \mid /c_s$ is the Mach number. Thus, and seeking to reduce the compressibility errors that arise when using the equilibrium distribution function (14), the authors in He and Luo (1997b) proposed a modified version of it:

$$f_i^{\text{eq}} = w_i\left\{\rho + \rho_0\left[3(\mathbf{c}_i \cdot \mathbf{u}) + \frac{9}{2}(\mathbf{c}_i \cdot \mathbf{u})^2 - \frac{3}{2}(\mathbf{u} \cdot \mathbf{u})\right]\right\}. \quad (15)$$

With the use of this equilibrium distribution, the incompressible Navier-Stokes equations are recovered, with approximation orders in terms of the Mach number (Daniel Reis Golbert 2009):

$$\nabla \cdot \mathbf{u} = 0 + O(M^2), \quad \text{e} \quad (16)$$

$$\frac{\partial \mathbf{u}}{\partial r} + \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla P + \overline{\nu}\nabla^2 \mathbf{u} + O(M^3), \quad (17)$$

where $P = c_s^2 \rho/\rho_0$ is the normalized pressure and $\overline{\nu}$ is the kinematic viscosity of the fluid, described by:

$$\overline{\nu} = \frac{2\tau - 1}{6}\frac{\Delta x^2}{\Delta t}. \quad (18)$$

It is noted that a value equal to 0.5 for the parameter τ implies in viscosity of the fluid identically null, situation not contemplated in the model. Values less than 0.5 indicate negative viscosities, which would be in disagreement with the laws of thermodynamics. From Eq. (18), we have:

$$\tau = 3\overline{\nu}\frac{\Delta t}{\Delta x^2} + \frac{1}{2}. \quad (19)$$

According to (Daniel Reis Golbert 2009), not found in the literature, a minimum value for the parameter τ guarantees the numerical stability of the method. Numerical instabilities appear when τ is close to 0.5.

D2Q9 Model

The lattice Boltzmann model known as D2Q9 has eight nonzero motion directions and the possibility of having a resting particle. It is a two-dimensional model, as illustrated in Fig. 2.

In the D2Q9 model, the time step is discrete, and for each lattice node, there are nine possible directions of motion, where $\mathbf{c}_0$ represents the lattice node itself, whose velocity is zero (Chen and Doolen 1998; Chopard et al. 2002). In this way, the number of possible directions is given by $z = 0, \ldots, 8$.

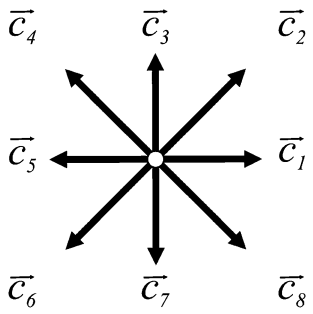
The eight possible velocities $\mathbf{v}_i$, given by Expression (6), are related to directions of movement $\mathbf{c}_i$ (Fig. 2), described by:

$$\begin{array}{lll} \mathbf{c}_0 = (0,0), & \mathbf{c}_1 = (1,0)v, & \mathbf{c}_2 = (1,1)v, \\ \mathbf{c}_3 = (0,1)v, & \mathbf{c}_4 = (-1,1)v, & \mathbf{c}_5 = (-1,0)v, \\ \mathbf{c}_6 = (-1,-1)v, & \mathbf{c}_7 = (0,-1)v, & \mathbf{c}_8 = (1,-1)v \end{array} \quad (20)$$

Two velocities are introduced, according to the distance to be traveled in a time step, namely:

- The slow velocities with module given by $v = \Delta_x/\Delta_t$ in the vertical and horizontal directions ($\mathbf{c}_1$, $\mathbf{c}_3$, $\mathbf{c}_5$, $\mathbf{c}_7$)
- Fast velocities with module $\sqrt{2}v$ in the diagonal directions ($\mathbf{c}_2$, $\mathbf{c}_4$, $\mathbf{c}_6$, $\mathbf{c}_8$)

This occurs due to the different distances that distributions must travel, in the same time interval, to reach the neighboring nodes.



Lattice Boltzmann Method for Fluid Simulation, Fig. 2 Direction of motion in the lattice of D2Q9

The update rule for the D2Q9 model follows the BGK model described in the Eq. (13). However, it is common to divide the dynamics of the LBM into two steps, namely: collision and scattering. Figure 3 illustrates the complete dynamics procedure divided into these steps.

The collision step is governed by the following equation:

$$f_i(\mathbf{x}, t + \Delta t) = f_i(\mathbf{x}, t)[1 - \tau] + \tau f_i^{\text{eq}}(\mathbf{x}, t). \quad (21)$$

The scattering step is governed by another equation given below:

$$f_i(\mathbf{x} + \Delta\mathbf{x}, t + \Delta t) = f_i(\mathbf{x}, t + \Delta t). \quad (22)$$

The general form of the equilibrium distribution function is described by Eq. (14). The author in (He and Luo 1997a) obtains the following values of weights ω_i and constants for the model D2Q9 (see Table 1):

$$f_i^{\text{eq}} = \rho\omega_i\left[1 + 3(\mathbf{c}_i \cdot \mathbf{u}) + \frac{9}{2}(\mathbf{c}_i \cdot \mathbf{u})^2 - \frac{3}{2}\mathbf{u}^2\right], \quad (23)$$

where:

$$\omega_0 = \frac{4}{9}, \quad \omega_i = \frac{1}{9}, \quad (i = 1, 3, 5, 7), \quad \omega_i = \frac{1}{36}, (i = 2, 4, 6, 8).$$

The macroscopic amounts of density (ρ) and velocity ($\mathbf{u}$) are given, respectively, by:

$$\rho(\mathbf{x}, t) = \sum_{i=0}^{8} f_i(\mathbf{x}, t), \quad (24)$$

$$\mathbf{u}(\mathbf{x}, t) = \frac{1}{\rho(\mathbf{x}, t)} \sum_{i=1}^{8} f_i(\mathbf{x}, t)\mathbf{c}_i. \quad (25)$$

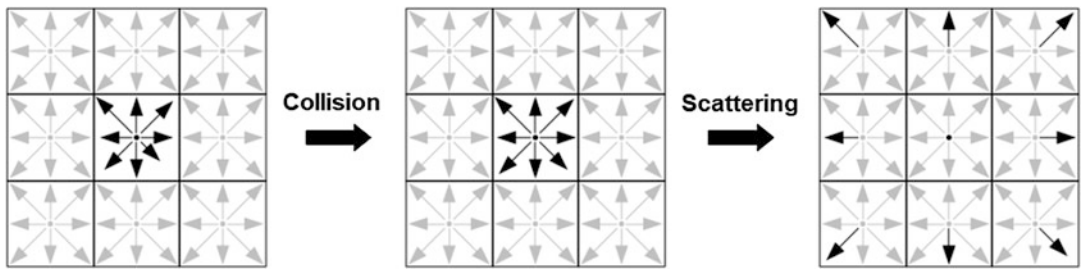
Boundary Conditions

Different types of contour conditions have been introduced in the field of hydrodynamics for the LBM. Bounce back is the simplest of them (Rothman and Zaleski 1997), used in boundary conditions whose walls are not slippery, that is, the nodes present in the walls present zero velocity in all directions. When the particles propagate to a boundary node, they simply return in the same direction they were.

Because of its simplicity, such a method cannot adequately represent curved boundary problems without introducing noise into the solution, especially in poorly refined lattices. An incorrect value may eventually cause a negative density value, generating an error that may accumulate along the evolution (Rothman and Zaleski 1997).

The periodic boundary condition is a simple option to apply. Basically, it is necessary to connect the ends of the domain according to the desired directions. Figure 4 shows the topologies of the domains when applying periodic boundary conditions in one direction and two directions in a two-dimensional model.

Another boundary condition is proposed by Zou and He (1997), where the authors impose velocity values (not necessarily null) on the



Lattice Boltzmann Method for Fluid Simulation, Fig. 3 Steps of LBM dynamics

centers of the border nodes. The basic idea is to introduce a step, between the collision step (21) and propagation step (22), to calculate the distributions in some directions of the boundary nodes.

After the propagation, the f_is from the interior and from the border itself are known at the border nodes. The unknown f_is as well as the density (ρ) of the boundary node are calculated from the mass conservation Eq. (24), of the linear momentum conservation Eq. (25), where boundary velocity is imposed, and through the reflection of the so-called non-equilibrium part (Zou and He 1997):

$$f_i - f_i^{\text{eq}} = f_{i+z/2} - f_{i+z/2}^{\text{eq}}, \tag{26}$$

where z represents the number of nonzero directions of the lattice. The D2Q9 model has $z = 8$.

To exemplify the abovementioned boundary condition, we show two-boundary situations in the D2Q9 model: boundary nodes present on the walls (Fig. 5a) and frontier nodes present in the corners of lattice (Fig. 5b).

The first situation shows the case of a border node present in the bottom wall. After the propagation (22), the distributions f_1, f_5, f_6, f_7, and f_8 are known, because they come from the neighboring nodes. According to the boundary condition proposed by Zou and He (1997), we will impose a velocity value (**u**) on the border nodes present on the bottom wall. To determine the four unknown variables (f_2, f_3, f_4, and ρ), we will use the mass conservation Eq. (24):

$$f_2 + f_3 + f_4 = \rho - (f_0 + f_1 + f_5 + f_6 + f_7 + f_8), \tag{27}$$

the conservation equations of linear momentum (25) in x direction:

$$f_2 - f_4 = \rho u_x - f_1 + f_5 + f_6 - f_8, \tag{28}$$

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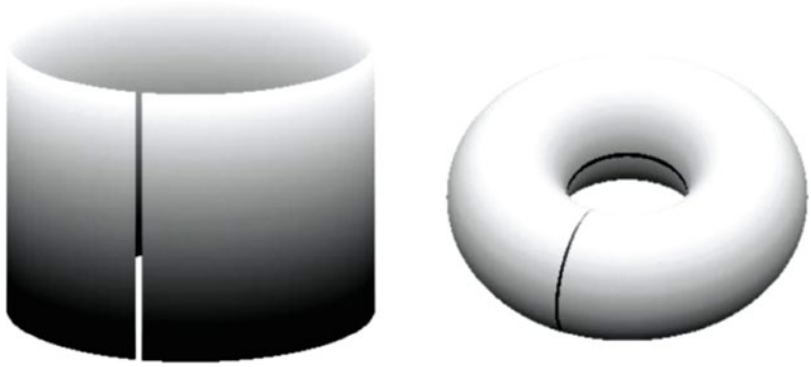
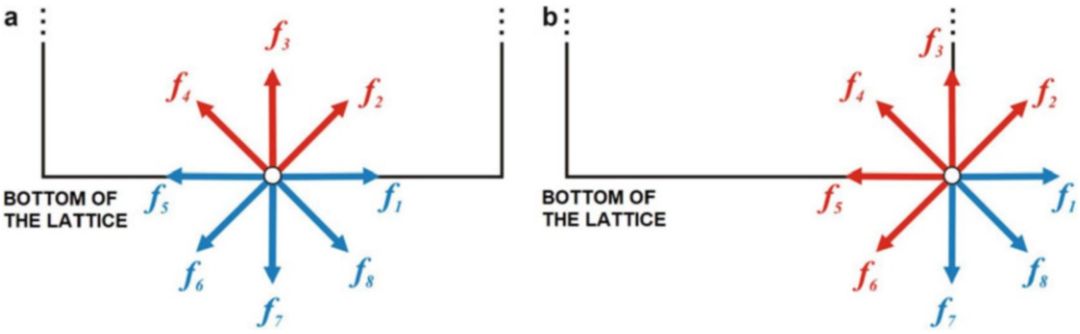


Lattice Boltzmann Method for Fluid Simulation, Fig. 4 Periodic boundary for one direction (left) and two directions (right)



Lattice Boltzmann Method for Fluid Simulation, Fig. 5 Boundary of D2Q9 model. (**a**) An example of a node present on the bottom wall. (**b**) An example of a node in the corner of the lattice

and y direction:

$$f_2 + f_3 + f_4 = \rho u_y + f_6 + f_7 + f_8. \quad (29)$$

From Eqs. (27) and (29), we have:

$$\rho = \frac{1}{1 - u_y} \times [f_0 + f_1 + f_5 + 2(f_6 + f_7 + f_8)]. \quad (30)$$

However, f_2, f_3, and f_4 remain indeterminate. In this way, we use the reflection of the non-equilibrium part of the distribution f_7:

$$f_3 - f_3^{eq} = f_7 - f_7^{eq}. \quad (31)$$

From Eqs. (27, 28, 29, 30, and 31) we can calculate the unknown variables:

$$f_3 = f_7 + \frac{2}{3}\rho u_y \quad (32)$$

$$f_4 = f_8 + \frac{1}{2}(f_1 - f_5) - \frac{1}{2}\rho u_x + \frac{1}{6}\rho u_y \quad (33)$$

$$f_2 = f_6 - \frac{1}{2}(f_1 - f_5) + \frac{1}{2}\rho u_x + \frac{1}{6}\rho u_y. \quad (34)$$

An analogous procedure is applied to the nodes that are present in the corners of the lattice. As an example, let's look at the node in the lower-right corner, as shown in Fig. 5b. After propagation (22), the distributions f_0, f_1, f_7, and f_8 are known. We will impose them a velocity value ($\mathbf{u}$), and to determine the six unknown variables (f_2, f_3, f_4, f_5, f_6, and ρ), we will use the mass conservation Eq. (24):

$$f_2 + f_3 + f_4 + f_5 + f_6 = \rho - (f_0 + f_1 + f_7 + f_8), \quad (35)$$

the conservation equations of linear momentum (25) in x direction:

$$f_2 - f_4 - f_5 - f_6 = \rho u_x - (f_1 + f_8), \quad (36)$$

and y direction:

$$f_2 + f_3 + f_4 - f_6 = \rho u_y + f_7 + f_8. \quad (37)$$

With three equations and six unknown variables, it is not possible to determine ρ. In this way, the density at the border node in the lower-right corner will be determined by the average of the neighboring densities. However, f_2, f_3, f_4, f_5, and f_6 remain indeterminate. We then use the reflection of the non-equilibrium part of the distribution f_1 and f_7:

$$f_5 - f_5^{eq} = f_1 - f_1^{eq}. \quad (38)$$

$$f_3 - f_3^{eq} = f_7 - f_7^{eq} \quad (39)$$

From Eqs. (35, 36, 37, 38, and 39) and the estimated density value (ρ), we are able to calculate the unknown variables:

$$f_3 = f_7 + \frac{2}{3}\rho u_y \quad (40)$$

$$f_5 = f_1 - \frac{2}{3}\rho u_x \quad (41)$$

$$f_4 = f_8 - \frac{1}{6}\rho u_x + \frac{1}{6}\rho u_y \quad (42)$$

$$f_6 = \frac{1}{2}(\rho - f_0) - (f_1 + f_7 + f_8) + \frac{1}{3}\rho u_x - \frac{1}{2}\upsilon u_y \quad (43)$$

$$f_2 = \frac{1}{2}(\rho - f_0) - (f_1 + f_7 + f_8) + \frac{1}{2}\rho u_x - \frac{1}{3}\rho u_y. \quad (44)$$

Algorithm 1 shows all the steps of the LBM methodology for the D2Q9 model.

Algorithm 1 D2Q9 Model algorithm.

```
        Dx = 50, Dy = 50, lattice[50]
[50]. f [9] //each node has 9 fi's
        // INITIALIZATION STEP
        density = 1.0
        velocity[50][50] = 0.0
        for each x in [0, Dx - 1] do
         for each y in [0, Dy - 1] do
           for each i in [0, 8] do
            lattice[x][y]. f [i] = f
eq(density, velocity[x][y], i)
           end for
         end for
```

```
        end for
        // SOLVER
        repeat
        // SAVE VELOCITY FIELD FOR STOP
CONDITION
         for each x in [0, Dx − 1] do
          for each y in [0, Dy − 1] do
            old[x][y] = velocity[x][y]
          end for
         end for
         // INNER LATTICE DYNAMICS
         for each x in [1, Dx − 2] do
          for each y in [1, Dy − 2] do
           Scattering of node [x][y] for
its neighbors
            Collision at node [x][y]
          end for
         end for
         Treats boundary conditions
         // STOP CONDITION
         max = 0
         for each x in [1, Dx − 2] do
          for each y in [1, Dy − 2] do
           norm = |velocity[x][y] − old
[x][y]|
            if (norm > max) then
       max = norm
            end if
          end for
         end for
        until (max >= delta)
```

Cross-References

- ▶ Cellular Automata Methods
- ▶ Fluid Simulation
- ▶ Lattice Gas Cellular Automata for Fluid Simulation

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Lattice Gas Cellular Automata for Fluid Simulation

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Synonyms

Cellular automata; Fluid simulation; Lattice methods; Numerical methods; Physics simulation

Definitions

- **Cellular automata**
  Mathematical models based on simple and local rules capable of generating complex behaviors.
- **Computational fluid dynamics (CFD)**
  Area of knowledge that studies computational methods to solve problems in fluid dynamics.
- **FHP**
  A specific cellular automata model to simulate fluid dynamics.
- **Lattice gas cellular automata (LGCA)**
  Cellular automata that simulates specifically fluid problems.

Introduction

In recent decades, techniques based on physical models for the animation of natural elements, such as fluids (gas or liquid), have drawn the attention of the researchers in computer graphics. The motivation lies in the potential in the applications of these techniques as well as in the complexity and beauty of the natural phenomena involved. In particular, techniques in the field of computational fluid dynamics (CFD) have been implemented for fluid animation.

Numerical methods in DFC for fluid simulation, such as finite differences and finite elements (Hughes 1987), try to describe a continuous system through the discretization of the equations that represent it. However, such methods have a high computational cost. Another alternative in this area is the use of techniques based on cellular automata (Wolfram 1994; Sarkar 2000; Kari 2005). Such methods seek to obtain the macroscopic dynamics of the fluid through the collective behavior of numerous microscopic particles. The specific cellular automata to simulate fluids are called lattice gas cellular automata (LGCA) and follow this idea by simplifying the dynamics through simple local rules for the interactions and displacement of the microscopic particles.

While traditional CFD modeling attempts to represent a continuous medium starting from macroscopic variables and partial differential equations (PDE), the LGCA modeling follows the inverse path, that is, from the microscopic description based on simple rules, it tries to obtain the macroscopic behavior (bottom up) without, however, explicitly solving any system of PDE (Chopard and Droz 1998). The macroscopic behavior is obtained through computational simulation, based on the set of rules governing the system, and simple interpolations.

LGCA can be seen as a simplified universe. Space is represented by a uniform lattice, where each cell contains Boolean data, the time step is discrete, and the laws governing that universe are expressed by simple rules of local collisions. They are discrete models, based on particles whose movement is restricted to the directions of the lattice edges. These methods have a lower computational cost and are more stable compared to the traditional ones used in fluid simulation, due to the fact that it is not necessary to calculate PDE to obtain the desired level of physical realism (Rothman and Zaleski 1997).

Among the varieties of automata of the LGCA type, this article will talk about the FHP model for its simplicity and computational efficiency (Chopard and Droz 1998). FHP was developed to simulate two-dimensional fluids. The space is discretized in a hexagonal lattice, that is, in each lattice node, there are six possible directions of movement. In addition, a multiscale technique was applied in order to demonstrate that the FHP model is capable of reproducing Navier-Stokes behaviors for two-dimensional fluids (Frisch et al. 1986).

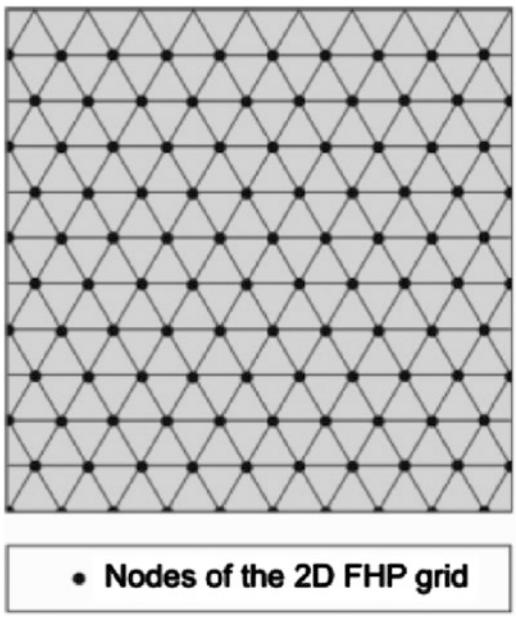
FHP Model

The FHP model was introduced by Frisch, Hasslacher, and Pomeau (Frisch et al. 1986), where FHP represents the name initials of their authors. It is a specific cellular automaton for fluid simulation, known as lattice gas cellular automata. Although the LGCAs cannot compete with traditional techniques of computational fluid dynamics, particularly for high Reynolds numbers, several authors have succeeded in using such

models to simulate complex systems, for which traditional techniques are difficult to apply (Chopard et al. 1998), such as porous media (Chen et al. 1991) and granular media (Krolyi and Kertsz 1994), among others (Boghosian et al. 1996). In addition, from the analysis of FHP microdynamics, through multiscale techniques, it is possible to obtain the traditional fluid dynamics equations (Appendix A) on a macroscopic scale (Frisch et al. 1986). These facts motivate the study of FHP as an alternative methodology for fluid simulation.

FHP is a two-dimensional model and can be seen as an abstraction, on a microscopic scale, of a fluid. The FHP describes the motion/interaction of particles in a discretized space in a hexagonal lattice, as seen in Fig. 1.

The microdynamics of FHP are given in terms of Boolean variables that describe the number of occupancy at each node of the lattice at each interaction step (i.e., the presence or not of particle). The particles move in discrete time steps, with a constant velocity in modulus, pointing along one of the six directions of the lattice. No more than one particle can move to the same lattice node, at a given instant, in a given direction. Such a constraint is called the exclusion principle, which ensures that six Boolean variables for each lattice node are sufficient to represent the microdynamics.



Lattice Gas Cellular Automata for Fluid Simulation, Fig. 1 The lattice of FHP model

Each particle moves at a constant velocity in modulus, in such a way that, in each interaction it traverses one edge of the lattice and reaches the neighboring node. In the absence of collisions, the particles keep moving along the direction specified by their velocity vector. Collisions occur when particles enter the same node at the same instant, resulting in a new local distribution of particle velocities.

When exactly two particles are incident on the same node with opposite velocities, both are deflected by an angle of 60° so that after the collision a new configuration is also made with zero momentum. Such a deviation may occur clockwise or counterclockwise, as shown in Fig. 2. For reasons of symmetry, the two possibilities are chosen randomly, with equal probability. When exactly three particles with velocities at an angle of 120° collide, each of them returns, toward the initial edge, as shown in Fig. 2. In this way, the moment remains null and is therefore preserved. For other configurations, the particles continue their movement as if there was no collision.

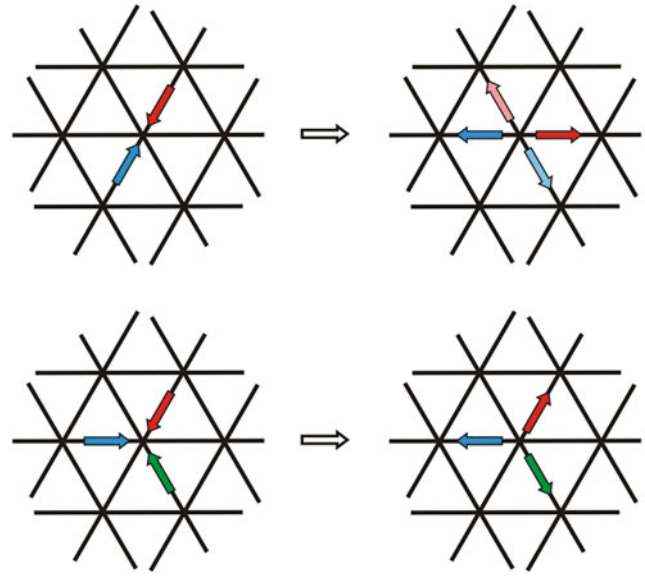
The FHP Microdynamic

The complete microdynamics of the FHP model can be expressed by an evolution equation for the occupation numbers, defined as the number $n_i(\mathbf{x},t)$ of particles entering the node $\mathbf{x}$ at instant t with velocity in the direction $\mathbf{c}_i$ (Chopard and Droz 1998):

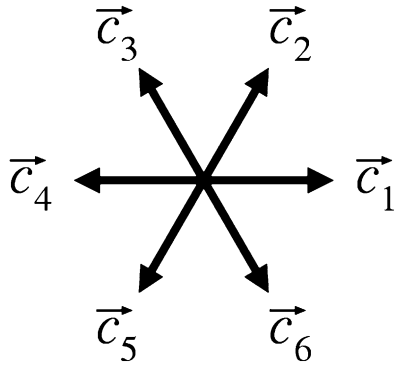
$$\mathbf{c}_i = \left(\cos\left(\frac{2\pi(i-1)}{6}\right), \sin\left(\frac{2\pi(i-1)}{6}\right)\right), \tag{1}$$

where $i = 1,\ldots,6$ represents the six possible directions for each lattice node, as shown in Fig. 3.

The numbers n_i can be 0 or 1, that is, presence or not of particle in the $\mathbf{c}_i$ direction of the lattice. Also defined is the time step as Δ_t and the



Lattice Gas Cellular Automata for Fluid Simulation, Fig. 2 Particle collisions in the FHP model



Lattice Gas Cellular Automata for Fluid Simulation, Fig. 3 Directions of movement in FHP lattice

displacement between lattice nodes as Δ_x. Thus, the six possible velocities $\mathbf{v}_i$ of the particles are related to their directions of motion by:

$$\mathbf{v}_i = \frac{\Delta_x}{\Delta_t}\mathbf{c}_i. \tag{2}$$

If there is no interaction between particles, the evolution equation for n_i can be written as (Chopard et al. 1998):

$$n_i(\mathbf{x} + \Delta_x\mathbf{c}_i, t + \Delta_t) = n_i(\mathbf{x}, t). \tag{3}$$

The Eq. 3 says that a particle entering the node $\mathbf{x}$ with velocity along $\mathbf{c}_i$ will continue in a straight line, in such a way that at the next instant it will enter the node $\mathbf{x} + \Delta_x\mathbf{c}_i$ with the same direction of motion (Chopard et al. 1998). However, when a collision occurs, one particle may be removed from its original direction or may be diverted to another. Let us look at the example of the collision described in Fig. 2, where exactly two particles compete for the same node with opposite velocities (top of the figure). In this case, before the collision, only n_2 and n_5 has 1 value in the $\mathbf{x}$ node. After the collision, we have two possibilities: n_1 and n_4 or n_3 and n_6 will have 1 value.

Generalizing for the collision between two particles with opposite velocities, the particle moving with velocity $\mathbf{v}_i$ before the collision will move with velocity $\mathbf{v}_{i-1}$ or $\mathbf{v}_{i+1}$, after the collision, where $i = 1,\ldots,6$ (note that operations on the index i must return values between 1 and 6). The binary quantity:

$$D_i = n_i n_{i+3}(1 - n_{i+1})(1 - n_{i+2})(1 - n_{i+4}) \times (1 - n_{i+5}) \tag{4}$$

indicates that a collision will occur when $D_i = 1$.

In fact, if there is a particle in direction $\mathbf{c}_i$ and one in direction $\mathbf{c}_{i+3}$, the term $n_i n_{i+3}$ will be 1. Thus it suffices that there is no particle in the other directions to ensure $D_i = 1$. Thus $n_i - D_i$

is the number of resultant particles in the $\mathbf{c}_i$ direction due to a collision of two particles along this direction.

However, when $n_i = 0$, a new particle may appear in direction $\mathbf{c}_i$, as a result of a collision between n_{i+1} and n_{i+4} or a collision between n_{i-1} and n_{i+2}. At this point, it is convenient to introduce a random Boolean variable $q(\mathbf{x}, t)$, whose value is used to decide whether a particle will be reflected to the right ($q = 1$) or to the left ($q = 0$). Thus, the number of particles created in $\mathbf{c}_i$ direction is given by:

$$qD_{i-1} + (1-q)D_{i+1}. \tag{5}$$

For the case shown in Fig. 2 of a collision between three particles, they can be scattered, with one of them occupying the direction $\mathbf{c}_i$. The amount (T) expressing the occurrence of a collision between three particles n_i, n_{i+2}, and n_{i+4} can be obtained by following the same principles above, given by:

$$T_i = n_i n_{i+2}\, n_{i+4}(1-n_{i+1})(1-n_{i+3}) \times (1-n_{i+5}). \tag{6}$$

Analogous to the previous case, the result of a collision between three particles is modify the number of particles in the direction $\mathbf{c}_i$. Thus, the number of resulting particles in $\mathbf{c}_i$ direction, considering the disappearance of a particle due to collision at position i or the appearance of a particle due to collision at position $i + 3$ can be expressed by:

$$n_i - T_i + T_{i+3}. \tag{7}$$

Once the collision rules have been stipulated, we can rewrite the Eq. 3 to the microdynamics of the FHP as:

$$n_i(\mathbf{x} + \Delta_x \mathbf{c}_i, t + \Delta_t) = n_i(\mathbf{x}, t) + \Omega_i(n(\mathbf{x}, t)), \tag{8}$$

where Ω_i is the collision term, defined from expressions (5) and (7):

$$\Omega_i = -D_i + qD_{i-1} + (1-q)D_{i+1} - T_i + T_{i+3}. \tag{9}$$

The Eq. 8 can be easily implemented, and the FHP model can be efficiently simulated in a computer. More elaborate collision operators can be created by including collisions between four particles or even by inclusion of a resting particle (Frisch et al. 1987). In general, the only constraint imposed is that the collision operator Ω_i preserves the mass $\sum_{i=1}^{6} \Omega_i = 0$ and the moment $\sum_{i=1}^{6} \mathbf{v}_i \Omega_i = 0$..

The Macroscopic Quantities

The physical quantities of interest are not the Boolean variables but the macroscopic quantities or the mean values, such as density and linear momentum at a point in the system (Chopard and Droz 1998). The distribution below corresponds to the probability of having a particle in the node $\mathbf{x}$, at instant t, with velocity $\mathbf{v_i}$ defined by the Eq. 2 (Chopard et al. 1998).

$$N_i(\mathbf{x}, t) = \langle n_i(\mathbf{x}, t) \rangle, \quad i = 1, \ldots, 6. \tag{10}$$

In general, an LGCA model is characterized by the z number of directions for each node of the lattice and the spatial dimension d. For a rectangular lattice with $d = 2$, we have $z = 4$, whereas for a hexagonal lattice we have $z = 6$. In some models there is the addition of a direction ($\mathbf{c}_0$), where $n_0 \in \{0, 1\}$ will be the number of particles at rest ($\mathbf{v}_0 = 0$) (Chopard and Droz 1998).

Following the usual definition of statistical mechanics, the local density of particles is the sum of the means of microscopic variables (expression 10):

$$\rho(\mathbf{x}, t) = \sum_{i=1}^{z} N_i(\mathbf{x}, t). \tag{11}$$

Similarly, the linear momentum ($\rho \mathbf{u}$) is given by (Chopard and Droz 1998):

$$\rho(\mathbf{x}, t)\mathbf{u}(\mathbf{x}, t) = \sum_{i=1}^{z} \mathbf{v}_i N_i(\mathbf{x}, t). \tag{12}$$

From these definitions and conservation laws, it is possible to estimate the macroscopic behavior of the system. For this, the multiscale expansion of Chapman-Enskog is used. The details of this technique can be found in the work of (Frisch et al. 1986). The result is the obtaining of mass and Navier-Stokes conservation equations from the microscopic dynamics of the FHP described in this section.

Cross-References

▶ Fluid Simulation

Appendix A

Mathematical Foundations

Conservation Laws

The most general conservation principles are the laws of mass conservation, moment, and the first and second laws of thermodynamics. Assuming that matter cannot be destroyed or created and despising sources, the amount entering a volume element equals the quantity that exits plus the amount accumulated in the element. This principle can be expressed in terms of transfer rates:

$$\text{Input rate} = \text{output rate} + \text{accumulation rate}.$$

The following is a review of the principles of mass conservation and movement. Initially, the general expressions of these laws will be developed for scalar and vector fields and then applied to the specific case of fluid mechanics.

Conservation Laws for Scalar Fields

Let U be a scalar quantity per unit volume, defined in an arbitrary volume Ω, fixed in space, and bounded by a closed surface S. The variation of the local intensity of U occurs due to the flow acting which expresses the contribution of the external medium to Ω and the Q sources. The general form of the conservation law for the scalar quantity U can be written as (Hirsch 1988):

$$\frac{\partial}{\partial t}\int_{\Omega} U d\Omega + \oint \mathbf{F}\cdot d\mathbf{S} = \int_{\Omega} Q_V d\Omega + \oint_{S} \mathbf{Q}_S \cdot d\mathbf{S}. \quad (13)$$

In Eq. 13, the first term to the left of the equality sign represents the U variation within the volume Ω per unit time. Such variation must be equal to the contribution of external medium due to the flow through the surface S, given by:

$$-\oint \mathbf{F}\cdot d\mathbf{S}, \quad (14)$$

plus the contributions of volumetric (Q_V) and surface ($\mathbf{Q}_S$) sources of U, expressed, respectively, by the terms to the right of the equal sign in the Eq. 13.

Assuming continuity of flow and surface sources, one can use the Gaussian theorem, also known as the divergence theorem, and rewrite the expression (13) as:

$$\int_{\Omega}\frac{\partial U}{\partial t}d\Omega + \oint_{\Omega}\nabla\cdot\mathbf{F} = \int_{\Omega} Q_V d\Omega + \oint_{\Omega}\nabla \cdot \mathbf{Q}_S d\Omega. \quad (15)$$

Equation 15 is in the integral form of the conservation law. The differential form is obtained directly from this, assuming any volume, and is given by:

$$\begin{aligned} &\frac{\partial U}{\partial t} + \nabla\cdot\mathbf{F} = Q_V + \nabla\cdot\mathbf{Q}_S \Rightarrow \\ &\frac{\partial U}{\partial t} + \nabla\cdot(\mathbf{F}-\mathbf{Q}_S) = Q_V. \end{aligned} \quad (16)$$

Conservation Laws for Vector Fields

For the case where the conserved amount is described by a vector quantity $\mathbf{U}$, then the flow and the term relative to the surface sources become tensors, $\overline{\overline{F}}$ and $\overline{\overline{Q}}_S$, respectively, and the term corresponding to the volumetric sources becomes a vector $\mathbf{Q}_V$. Equations 15 and 16, respectively, assume the form (Hirsch 1988):

$$\int_{\Omega} \frac{\partial \mathbf{U}}{\partial t} d\Omega + \oint_{\Omega} \nabla \cdot \overline{\overline{F}} d\Omega = \int_{\Omega} \mathbf{Q}_V d\Omega + \oint_{\Omega} \nabla \cdot \overline{\overline{Q}}_S d\Omega, \quad (17)$$

$$\frac{\partial \mathbf{U}}{\partial t} + \nabla \cdot \left(\overline{\overline{F}} - \overline{\overline{Q}}_S \right) = \mathbf{Q}_V. \quad (18)$$

Mass Conservation Equation

The partial differential equation that expresses conservation of mass is also known as the continuity equation. Applying the conservation law given by the Eq. 15 for the particular case where U is the mass density density (ρ), we have:

$$\int_{\Omega} \frac{\partial \rho}{\partial t} d\Omega + \oint_{\Omega} \nabla \cdot (\rho \mathbf{v}) = \int_{\Omega} Q_V d\Omega + \oint_{\Omega} \nabla \cdot \mathbf{Q}_S d\Omega, \quad (19)$$

where $\mathbf{v}$ is fluid velocity. In the differential form, we have:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = Q_V + \nabla \cdot \mathbf{Q}_S. \quad (20)$$

In the absence of sources, the continuity equation takes into account only the density and velocity of the fluid. It can be applied to all fluids, compressible and incompressible and Newtonian and non-Newtonian (Shaughnessy et al. 2005). For incompressible fluids, the density is constant, that is, it is not a function of the spatial coordinates nor of the time. The Eq. 20 results in:

$$\nabla \cdot \mathbf{v} = 0. \quad (21)$$

Another particular case occurs when the density is independent only of time, resulting in:

$$\nabla \cdot (\rho \mathbf{v}) = 0. \quad (22)$$

Moment Conservation Equation

The linear momentum, defined by ($\rho \mathbf{v}$), is a vector quantity, and therefore its conservation law has the general form given by Eqs. 17 and 18. The central issue now is to determine the tensors $\overline{\overline{F}}$ and $\overline{\overline{Q}}_S$ and the vector $\mathbf{Q}_V$ that appear in these equations.

By Newton's second law, it is known that the agents responsible for the linear momentum of a physical system are the forces acting on it. Such forces may be external or internal. Let us then consider a portion of fluid bounded by a surface S.

As external forces, we can have force fields such as the gravitational field and electromagnetic field. Let $\mathbf{f_e}$ be the volumetric density of the resultant of these forces. In addition to external forces to the system, we also have internal forces due to deformations and internal tensions of the same. In this text, it is assumed that the fluid is Newtonian, that is, that the internal stresses are given by the expression (Hirsch 1988):

$$\overline{\overline{\sigma}} = -p\overline{\overline{I}} + \overline{\overline{\tau}}, \quad (23)$$

where $\overline{\overline{I}}$ is a unit tensor, p is the hydrostatic pressure, and $\overline{\overline{\tau}}$ is the tensor of tensions whose components are given by (Hirsch 1988):

$$\tau_{ij} = v\left[\left(\partial_i v_j + \partial_j v_i \right) - \frac{2}{3} (\nabla \cdot \mathbf{v}) \delta_{ij} \right], \quad (24)$$

where v is the kinematic viscosity.

By integrating (23) along S, we have the resultant of the internal forces to the fluid that act on the volume Ω. As for the tensor $\overline{\overline{F}}$, this will be given by (Hirsch 1988):

$$\overline{\overline{F}} = \rho \mathbf{v} \otimes \mathbf{v}, \quad (25)$$

where:

$$\mathbf{v} \otimes \mathbf{v} = \begin{pmatrix} v_1 v_1 & v_1 v_2 & v_1 v_3 \\ v_2 v_1 & v_2 v_2 & v_2 v_3 \\ v_3 v_1 & v_3 v_2 & v_3 v_3 \end{pmatrix}, \quad (26)$$

with $\mathbf{v} = (v_1, v_2, v_3)$.

Thus, the expression (17) takes the form:

$$\int_{\Omega} \frac{\partial(\rho \mathbf{v})}{\partial t} d\Omega + \oint_{\Omega} \nabla \cdot (\rho \mathbf{v} \otimes \mathbf{v}) d\Omega = \int_{\Omega} \rho \bar{f}_e d\Omega + \oint_{S} \bar{\bar{\sigma}} d\mathbf{S}. \quad (27)$$

Substituting $\bar{\bar{\sigma}}$ with the expression (23) gives the integral form of the conservation law of linear momentum for a Newtonian fluid. The corresponding differential expression is obtained directly from the integral form, given by (Hirsch 1988):

$$\frac{\partial(\rho \mathbf{v})}{\partial t} + \nabla \cdot \left(\rho \mathbf{v} \otimes \mathbf{v} + p\bar{\bar{I}} - \bar{\bar{\tau}} \right) = \rho \bar{f}_e. \quad (28)$$

Subtracting the Eq. 20 from the left side of the Eq. 28, multiplied by ρ, and assuming the source terms are null, we find:

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla p + \nabla \cdot (\bar{\bar{\tau}}) + \rho \bar{f}_e, \quad (29)$$

where $D\mathbf{v}/Dt$ is the material derivative, given by:

$$\frac{D\mathbf{v}}{Dt} = \frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v}. \quad (30)$$

When the expression (24) for the tensor of tensions of a viscous Newtonian fluid is replaced in Eq. 29, we obtain what we call **Navier-Stokes equations**. For constant viscosity coefficients, this equation reduces to:

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla p + v \left[\Delta \mathbf{v} + \frac{1}{3} \nabla (\nabla \cdot \mathbf{v}) \right] + \rho \bar{f}_e. \quad (31)$$

For incompressible fluids ($\nabla \cdot \mathbf{v} = 0$), the Eq. 31 reduces to:

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla p + v \Delta \mathbf{v} + \rho \bar{f}_e. \quad (32)$$

In the case of an ideal fluid without internal stresses, and therefore without viscosity $v = 0$, the Eq. 32 reduces to the call **Euler equation**:

$$\rho \frac{D\mathbf{v}}{Dt} = \rho \frac{\partial \mathbf{v}}{\partial t} + \rho (\mathbf{v} \cdot \nabla) \mathbf{v} = -\nabla p + \rho \bar{f}_e. \quad (33)$$

Therefore, we find the equations of mass conservation and Navier-Stokes, given, respectively, by:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = Q_V + \nabla \cdot \mathbf{Q}_S \quad (34)$$

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla p + v \left[\Delta \mathbf{v} + \frac{1}{3} \nabla (\nabla \cdot \mathbf{v}) \right] + \rho \bar{f}_e. \quad (35)$$

Such equations form the basis for describing the behavior of a fluid, particularly for computer graphics animations.

Cross-References

▶ Fluid Simulation

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Lattice Methods

▶ Lattice Gas Cellular Automata for Fluid Simulation

LBM

▶ Lattice Boltzmann Method for Diffusion-Reaction Problems
▶ Lattice Boltzmann Method for Fluid Simulation

Learning

▶ Immersive Virtual Reality Serious Games

Learning Agents

▶ Machine Learning for Computer Games

Learning Analytics

▶ Design Framework for Learning to Support Industry 4.0

Learning Challenges

▶ Challenge-Based Learning in a Serious Global Game

Learning Disabilities

▶ Making Virtual Reality (VR) Accessible for People with Disabilities

Learning Disability

▶ Computer Games for People with Disability

Learning Framework

▶ Design Framework for Learning to Support Industry 4.0

Legend of Zelda Breath of the Wild and the Lens of Curiosity

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Synonyms

Action-adventure game; open-world game

Definitions

Action-adventure game = a video game that combines elements from both action game and adventure game.

Open-world game = a video game featuring a virtual world in which the player can explore and play freely without linear and structured gameplay.

The Lens of Curiosity

The Legend of Zelda: Breath of The Wild is a game where the players' curiosity can change their path and the way they think of the worlds' origins. When playing Breath of the Wild players can easily find themselves climbing tall mountains and staring into the distance wondering what that other mountain could hold or what this oddly shaped rock may be. The way Breath of the Wild can bend players' minds is very intriguing.

In Jesse Schell's book *The Art of Game Design: A Book of Lenses*, the Lens of Curiosity states that "to use this lens, think about the player's true motivations — not just the goals your game has set forth, but the reason the player wants to achieve those goals." (Schell, 2019) The Lens of Curiosity requires us to ask the following these questions:

1. What questions does my game put into the player's mind?
2. What am I doing to make them care about these questions?
3. What can I do to make them invent even more questions?

At the start of the game The Legend of Zelda: Breath of The Wild, the main character Link awakens from a slumber and walks out of a cave to find this massive and expansive world that makes the player think, "What's in this huge world, where is everyone, and how do I start pursuing this world?" Every so often the game throws something that can catch a curious gamer's eye; like a sparkle off the side of a road or a bright beacon being shot into the sky. These moments are what really make the game's world so immersive and give the player a variety of things to do. For example, there are these creatures known as the Korok that give the player a Korok Seed that can be used to expand Link's inventory by giving him more slots to store weapons, items, etc. These seeds can be found by solving puzzles or just flat out finding them by flipping over rocks or shooting specific objects with Link's bow. Giving the player the choice to find these leads to the player asking, "Will finding these benefit me or just be a waste of time?" There is also a story behind the world and why it has been cleansed of most of its people and why a lot of the land is in ruins.

At the start of the game, the player is given the option to head straight to the final boss of the game, and while they can do this, it makes the game way harder for the player and leaves the player with more questions than answers when they beat the final boss. They are also given the option to go to a character named Impa that will lead them on a path to experience the world more and dive deeper in the past that Link has experienced.

Sure the player can beat the game right off the bat, but what about the rest of the world? Should they become stronger and master the games mechanics, maybe experience more of Link's memories? It is all up to the player. The player cares about these questions the further they get into the game, giving the player crucial choices that can leave the player on the brink of survival or on the path to destroying the evil Calamity Ganon.

The player's mind is what turns this game into an experience. Players find themselves experiencing more and more of the world by solving a question they asked maybe a couple hours earlier. These are just some of the questions the player will ask themselves as they play Breath of the Wild. With so much to uncover in the world and so many things to experience, one could say there is nearly an infinite amount of questions. Ultimately, Breath of the Wild asks the player how they will go about choosing a path in this expansive world. Where and how high will the player set their stakes and why are they setting them where they are?

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Length of View

► 3D-Rendered Images and Their Application in the Interior Design

Lens

► 3D-Rendered Images and Their Application in the Interior Design

Life Simulation Game

► Animal Crossing: New Horizons and Its Popularity During COVID-19 Pandemic
► The Sims Franchise, a Retrospective of Racial Representation and Skin Tones

Life-Size Telepresence

► Life-Size Telepresence and Technologies

Life-Size Telepresence and Technologies

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Synonyms

Digital communication; Life-size telepresence; Telepresence

Definition

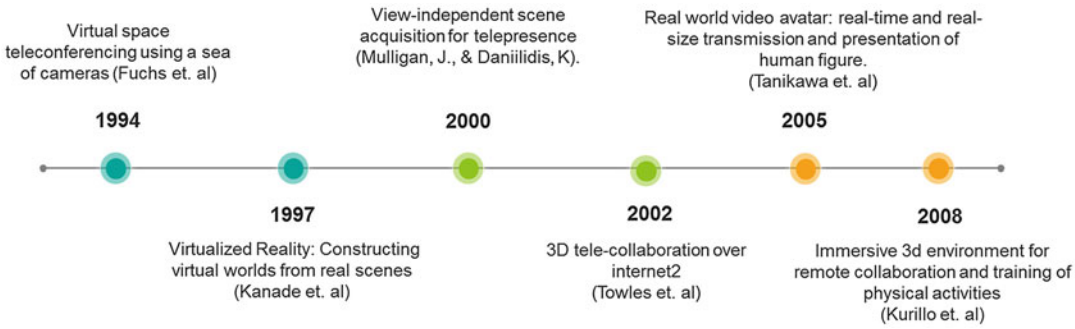
Telepresence technology refers to using a communication medium to give the impression of being present in an environment. Advancements in modern communication, media, and Internet have allowed for the widespread adoption of this technology. Using this technology can help to save both time and money while also reducing environmental damage because it can be used as an alternative to traveling to present at conferences or other meetings. Telepresence systems have the potential to make it easier for individuals who are separated by distance to communicate with one another.

It can be helpful in the world of business, education, and medicine, for example, allowing nonexperts to perform complicated tasks under the guidance of professionals. A user's size has been found to significantly influence the outcomes of human communication aspects. If the user is displayed in life size, there is a good chance that social relationships, for example, power or dominance and persuasiveness, will be more evenly distributed and natural. Therefore, this entry discusses life-size telepresence and other technologies such as videoconferencing and holographic telepresence.

Introduction

Telepresence is a technology that allows the user to feel present at a specific location when he remotely transfers himself through digital representation (Fadzli et al. 2020). It uses a technique that utilizes necessary multimedia such as sounds, visions, and touch to create a sense of physical presence at remote locations (Shen and Shirmohammadi 2006). Telepresence is also known as virtual representation, where the term "tele" in telepresence refers to telecommunication technology (Kittler 2021), and the term "presence" in telepresence refers to the experience of existing in one place or environment (Witmer and Singer 1998).

Figure 1 shows the timeline progress of the telepresence system from Fadzli et al. (2020)).


Virtual space teleconferencing using a sea of cameras (Fuchs et. al)
1994
1997
Virtualized Reality: Constructing virtual worlds from real scenes (Kanade et. al)
View-independent scene acquisition for telepresence (Mulligan, J., & Daniilidis, K).
2000
2002
3D tele-collaboration over internet2 (Towles et. al)
Real world video avatar: real-time and real-size transmission and presentation of human figure. (Tanikawa et. al)
2005
2008
Immersive 3d environment for remote collaboration and training of physical activities (Kurillo et. al)

Life-Size Telepresence and Technologies, Fig. 1 Chronological progress of telepresence (Fadzli et al. 2020)

According to the timeline, the early phase of telepresence is the virtual space teleconferencing using a lot of cameras to acquire the photometric and depth information (Fuchs et al. 1994). Three years after, Kanade et al. (1997)) constructed a virtual world from real scenes for the viewer to view continuous motion in a virtual sequence. However, there are discontinuities in virtual image motion. Thus, Mulligan and Daniilidis (2000)) proposed view-independent scene acquisition for telepresence. Furthermore, Towles et al. (2002)) provided the 3D telecollaboration over Internet2 because the view-independent scene acquisition required transmission of rendered 3D world. However, there is a hardware restriction and limitation on the display setup, making Tanikawa et al. (2005) introduce real-time and real-size transmission and presentation of a human figure. In this the person's image is captured by multiple cameras, transmitted through the network, and displayed on a revolving flat panel (Tanikawa et al. 2005). However, the issues did not stop here. There are overlapped between the viewer and the display system. Hence, Kurillo et al. (2008) produced an immersive 3D environment for remote collaboration and training of physical activities that are able to perform real-time 3D construction of users.

Life-Size Telepresence

Telepresence space can support nonverbal communication such as body language, eye gaze, and facial expression because it has a free viewpoint video combined with immersive projection technology (Fairchild et al. 2016). Besides that, it allows users to do so in such a way that users have the same transparent sense of appropriateness of space to activity. One of the examples of telepresence space by Beck et al. (2013) is in which there is a telepresence space where two groups of users meet virtually in a life-size 3D representation of the remote user. Figure 2 shows an example of a remote user in telepresence space.

One of the issues of concern is telepresence using holoportation technology (Orts-Escolano et al. 2016) requires the user to wear HMD in telepresence space. The use of cumbersome hardware such as HMD limits face-to-face communications (Regenbrecht et al. 2004). The small display optic in front of each eye in HMD and narrow field of view (FOV) make the device have a limitation for gaze input in face-to-face communications. Besides that, wearing HMD can be very uncomfortable for participants. According to Kooi et al. (Kooi and Toet 2004), binocular display systems such as HMD shows a different image to the left and right eye, which can affect viewing comfort. Users feel discomfort and have motion sickness. Figure 3 shows an example of telepresence space using HMD and performing remote collaboration.

The uncanny valley (MacDorman and Chattopadhyay 2016) is a phenomenon that occurs when human replicas stimulate unintended cold, eerie emotional responses in viewers. The effect was first proposed in 1970 by Masahiro

Life-Size Telepresence and Technologies, Fig. 2 Telepresence space with a remote user

Mori, who associated it with discrepancies in the replica's realism, with some features represented as human and others as nonhuman (Mori 1970). According to Jones et al. (2021), the uncanny valley of telepresence is characterized by a sharp drop in the continuous increase of both local and remote users' experience of belonging as a telepresence experience becomes more like a physical presence. Yu et al. (2021) argue that overcoming the "Uncanny Valley of Telepresence" will entail identifying the gestalt of what is most accountable about the comfort of belonging with others. Based on their findings, there is a similar concept of the uncanny valley of telepresence, which states that the higher the simulation level of a telepresence experience, or the more it tries to simulate or replicate actual presence, the greater the user's feeling of "belonging to the space," up to a turning point. The user's experience begins to decline at this point. The illusion of "being there" raises the expectations of their own abilities in the space, but when those expectations are not met, they become frustrated and believe they are not meant to be there. In other words, they have a diminished sense of "belonging" there.

Life-Size Telepresence and Technologies, Fig. 3 3D teleportation remote collaboration in real time

Yu et al. (2021) propose a different interpretation of uncanny valley related to telepresence, claiming that the level of coherence may have influenced the perception of the remote participants perceiving the presented avatar. For example, MacDorman and Chattopadhyay (2016) claim that decreasing consistency in human realism in avatar images increases the perception of uncanny valley categories. A similar aspect could be argued for their study; while the 3D virtual character avatar was not entirely out of consistency with the environment, it is clear that the point cloud representation avatar was exactly fitting the style and presentation of the environment reconstruction, as the same system was used for the avatar and for the environment. The result shows that in order to choose the representation of the user, we need to consider the way the environment was represented as well.

Telepresence can be projected in many sizes, either small or large. In order to achieve a great augmented reality collaboration environment, life-size telepresence can be considered the perfect size. Life-size telepresence has the same measurement as a real-life size. This will help the participants to feel more realistic and feel presence in the remote location as according to Pejsa et al. (2016).

Based on Mark and DeFlorio (2001) research, the large ratio of life-size telepresence supports the interaction for both sites. When the interaction between each side is supported, both participants have a better experience in communication through the projection of holograms based on the experiment that has been conducted where there are two groups of people; group A sat in Room A and watched the projection of group B in Room B. Besides that, Pejsa et al. (2016) have claimed that life-size telepresence makes the participants appear as if they are inhabiting the same space. This facilitates more natural interaction since people can fully see each other and improve nonverbal signals such as gaze, body language, and gestures. The life-size virtual copies of remote participants are projected into physical space, as shown in Fig. 4.

Comparison Between Telepresence and Videoconference

This section shows the difference between audioconferencing, videoconferencing, and telepresence. Videoconferencing began in 1964 when AT&T unveiled the picturephone at the New York World's Fair, the world's first videoconferencing endpoint. In the year 2000, telepresence systems hit the market, bringing a more realistic approach to face-to-face meetings. However, they are not

Life-Size Telepresence and Technologies, Fig. 4 Augmented image in life-size telepresence

concerned with price but rather with providing customers with a high-quality, fully immersive experience (Pulido 2011). This shows that videoconference exists before telepresence and that telepresence is the advanced technology where it produces a better quality of video and facial expression of the user. In comparison, videoconferencing produces low to medium video resolution and displays in TV quality.

In recent years, real-time telepresence has attracted more and more attention. However, this technology has several issues that cannot be avoided. One of the issues is that participants must travel to facilities that are equipped and staffed to produce telepresence videoconferences (Fuchs et al. 2014). This is an issue for the user that is traveling. They need to find a place that has the equipment of the telepresence or prepare the set of the telepresence equipment at their place.

Although the risk of disruption or failure is extremely low, it is always possible over the Internet (Takamizawa et al. 2004). Coverage of the Internet depends on the location of the user. If the user location has low coverage of the Internet, the possibility for failure over the Internet is high. Users cannot perform telepresence without the Internet. Disruption Internet also can occur during telepresence. The comparison table is produced by Davis and Kelly (2008). Table 1 lists a comparison of three terminologies based on their characteristics, videoconferencing, HD videoconferencing, and telepresence.

Technologies

This section will discover the technologies used for telepresence.

Videoconferencing

Telepresence has brought a revolution in the communication industry. The advancement of telepresence technology has changed the way we are able to communicate and connect with each other. One of the advancements of telepresence technology is videoconference technology. Telepresence technology is a system that provides a life-size, high-definition video and stereo-quality audio, and make people experience face-to-face interaction at a distance (Pulido 2011). Figure 5 shows an example of videoconference technology, and this type of technology is very common in a meeting room.

Holographic

The next technology is holographic telepresence technology. Holographic technology provides full motion of projection, as well as realistic and 3D images in real-time. As stated by Luevano et al. (2019), a holographic telepresence system captures and compresses images of real, remote people or surrounding objects and transfers images together with the sound across the Internet. Holographic use the method of recording patterns of light and projecting the pattern in a three-dimensional image

Life-Size Telepresence and Technologies, Table 1 Comparison of the three terminologies

Characteristic	Videoconferencing	HD videoconferencing	Telepresence
Cost	Free to $100 s	$1000s	$10 k to $100ks
Picture quality	Poor to good	Good to excellent	Excellent
Bandwidth requirement per endpoint	100 s of kilobits per second	100 s of kilobits per second to megabits per second	1 Mbps to 50 Mbps+
No. of participants	Usually two	Two or more	Many
Interoperability with other systems	Common	Limited	Very limited
Camera position	Fixed or variable	Fixed or variable	Usually fixed
Room footprint	Variable	Variable	Fixed and requires room preparation
Platform	Software and hardware	Usually hardware	Hardware

called hologram (Elmorshidy 2010), and Fig. 6 shows the example of holographic projection.

Other than that, the projector camera is also another type of telepresence technology. This technology has the potential for remote individuals to view each other's environment and also communicate by overlaying the user's virtual copy image in new ways into the remote location,

Life-Size Telepresence and Technologies, Fig. 5 Example of videoconferencing

Life-Size Telepresence and Technologies, Fig. 6 Holographic telepresence using projector-based images

Life-Size Telepresence and Technologies, Table 2 Comparison of the three terminologies

Type	Advantages	Disadvantages
High-definition	High resolution	Flat images
3D display	High-resolution Stereoscopic	Narrow viewing angles Require glasses to display Not in 3D imagery
3D holographic display	"Life-like" picture Volumetric 3D display Interactivity	Require a large amount of processing Constraint by the size of holographic material Production cost is expensive

without wearing any specialized device on the user (Pinhanez and Pingali 2004). Projector-camera-based technology by Pinhanez et al. (Pinhanez and Pingali 2004) is much more simple than holographic. The cost required for application setup is also low and suitable for telepresence.

Table 2 shows the advantages and disadvantages between high-definition, 3D displays, and 3D holographic display. Based on the table, 3D holographic displays have a lot of advantages compared to other technology. However, the production cost to set up a holographic is expensive.

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Lifestyle Brand

► Professional Call of Duty Player Matthew "Nadeshot" Haag: An e-Sports Case Study

Linear Solving of Apollonius problem

► Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems

Linear Solving of Dupin Problem

► Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems

Live Texture Mapping in Handheld Augmented Reality Coloring Book

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Synonyms

Augmented reality; Live texturing; Texture mapping

Definition

Nowadays, many coloring books have been using augmented reality (AR) as the enabler to display virtual objects in the real world. Real-time texture mapping is an essential element that brings AR coloring more advanced. The augmented 3D character is textured according to the video stream coloring. Act as a guideline to deliver real-time texturing mapping for augmented reality coloring applications. This entry explains the live texturing process in AR, the live texture mapping for the AR coloring book.

Introduction

AR is growing not just in entertainment but also in education. AR books are a product that uses AR technologies and becomes new development of entertainment and educational models.

An interactive augmented coloring book introduced by Clark et al. (2012) is additionally one of the real leaps forward of AR education. The technology features the significance of direct intuitiveness with the content by enabling the user to control the result AR 3D content with their shades of shading, giving more impact on the learning strategy since interactivity promotes learning by activating specific cognitive processes (Nor'a et al. 2019).

AR books can become physical or digital copies with both text and illustrations. Technology usage, such as smartphones or tablets, can display the 3D content on top of the AR book. This augmentation can be achievable once the camera points toward the page of the AR Book. Usually, the AR Book will provide the mobile application to be downloaded by the smartphone that allows the application to track the page and display the content based on the page that we track. A video clip, audio clip, image, or even 3D object can become one of the AR content that the AR Book can display.

HITLab NZ. ColAR has researched the idea of the AR book for more than 10 years which allows users to color the book page and view the 3D model in the real world with colored textures (Cho et al. 2016). Usually, the AR color book requires a paper book and smartphone application to use with the AR book. The user needs to color the paper book first before the texture is mapped onto a 3D character and displayed in an AR environment. With the AR coloring book, the children can view 3D animation of the character and painted color when they use a smartphone to take real-time video.

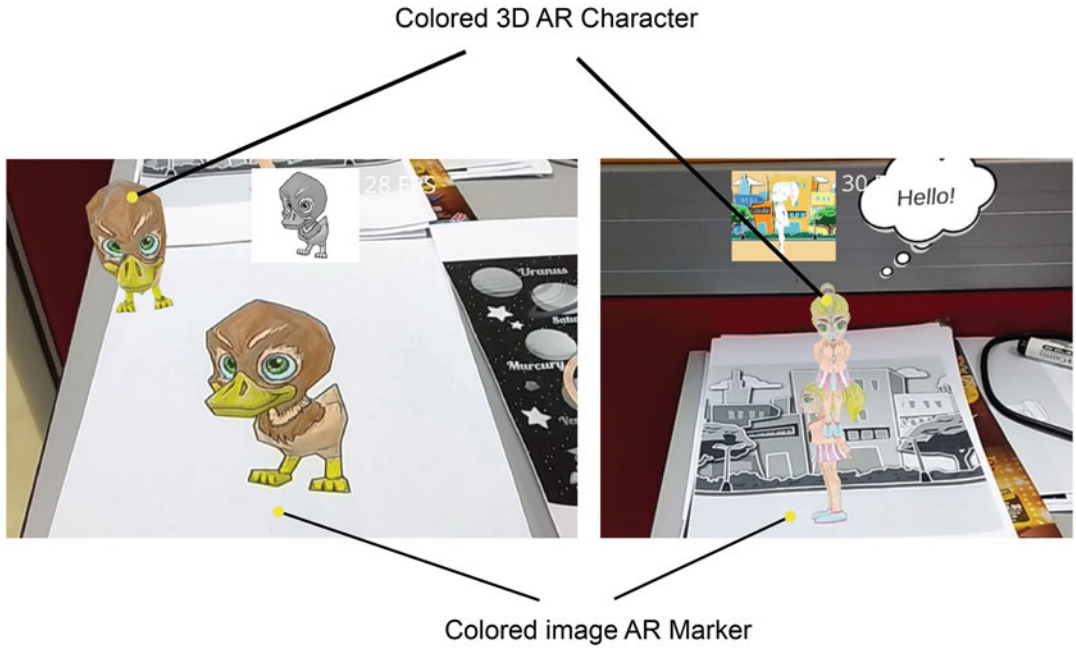
Quiver created a ColAR application that already sells coloring page through the online market, and users can download the application from the apps store to view 3D characters in the AR environment after they color it. The Korea-based company AIARA also produces an AR coloring book that combines the AR and Internet of Things (IoT), allowing the merge of analogue and digital media.

Live Texture Mapping in AR

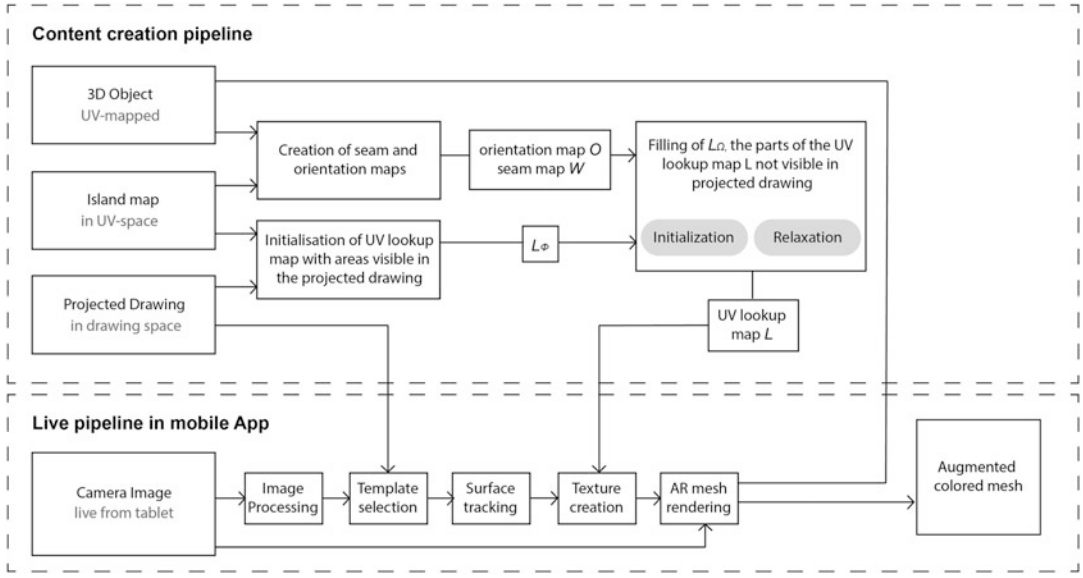
Earlier work has been found in Clark et al. (2012) when they create scenes in 3D and textured models that refer to user creation. After that, actual book pages will become the base for placing the 3D content in the real world. With this, the user can feel a 3D experience with their content. Figure 1 shows the two examples of the AR character as 3D content on top of the page. In 2015, the enhancement suggested a live texturing process, and it has been defined in Magnenat et al. (2015) as illustrated in Fig. 2. As described in Zhao et al. (2017), it presented a texture process that generates a texture map for 3D augmented reality characters from 2D colored drawings using a lookup map. Considering the movement of the mobile device and drawing, they have given an efficient method to track the drawing surface.

Figure 2 shows the adapted pipeline defined in Magnenat et al. (2015) of the static content creation and live surface tracking, texturing, and rendering pipelines. The pipeline has stated that it needs to be run only once. A live pipeline tracks the drawing and overlays the augmented character on top of it, with a texture created from the drawing in real-time using the lookup map. As in Fig. 2, in the Live Pipeline box, the camera image captures a set of colored drawing pages. Five boxes have been running through, and the following points described all the processes involved:

- **Image Processing**. The input image converts the colored page into grayscale and uses image processing to produce drawing lines. The black line has been produced by applying adaptive thresholding. Figure 3 shows the process involved.

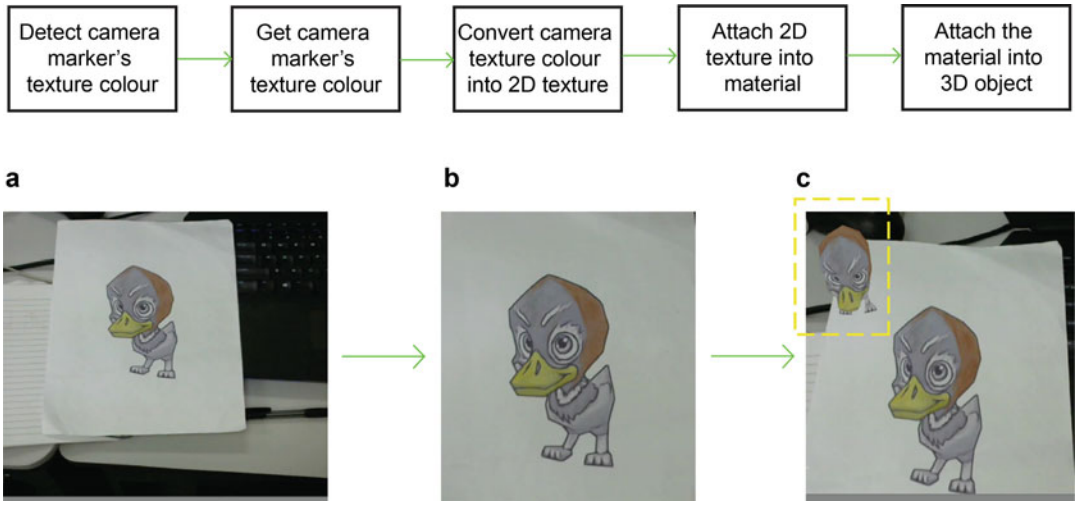


Live Texture Mapping in Handheld Augmented Reality Coloring Book, Fig. 1 3D content on top of the page



Live Texture Mapping in Handheld Augmented Reality Coloring Book, Fig. 2 Live texturing pipeline in AR Color Book

- **Template selection**. It shows the content pipeline where the UV mapping has been implemented to quickly patch the image into characters so their textures will correspond to what has been drawn. Here it is called a real-time painting.
- **Surface tracking**. The template that has been selected needs to retrieve the reference images,



Live Texture Mapping in Handheld Augmented Reality Coloring Book, Fig. 3 Image processing: (**a**) Colored image. (**b**) Marker texture color for image processing. (**c**) 3D AR object with colored texture

and this surface tracking will align the camera with the captured image to render the reference image.

- **Texture creation and mesh rendering**. Used when to open the camera, there will be a real live environment as a background image for AR scene, and pose estimation to render the 3D scene with the live texture mapping in real-time.

Image Inpainting Technique

Image inpainting is defined as a process to restore the damaged area of the image. Several kinds of research have been done to reconstruct images from message overlay or scratches, loss concealment in an image, and occlusion problem when rendered after the camera captured the image (Casas et al. 2017). Marker hiding has been studied to hide markers when the camera tracked the marker (Korkalo et al. 2010).

In image inpainting, there are still some problems concerning ill-posed inverse issues with no well-defined unique solution. It is necessary to define image priors to solve the problem. This method assumes the pixel from the known and unknown parts to have the same measurable properties or geometrical complexes. From that point onward, this will be converted into various local or global priors to have an inpainted image as physically logical and visually satisfying as expected (Guillemot and Le Meur 2013). The diffusion-based inpainting method denotes the image's unknown part and fills in with the source from the known region. These methods are generally relevant for accomplishing straight lines and curves and inpainting small areas conceivable (Guillemot and Le Meur 2013).

The term diffusion comes from using the smoothness priors, which come from proliferating nearby data by analogue with physical marvels like warmth proliferation in physical structures and smoothness constraints. Inpainting utilizing dispersion easily spreads nearby picture structures from the outside to the inside of the gap, "emulating" the motion of expert painting restorators (Guillemot and Le Meur 2013). It then uses the considered data to assume smoothness limitation and iteratively regularized and creates a smoother image in an endless array. However, diffusion-based is not suitable for the recovery texture of large areas, and it also tends to be a blur. The inpainting process is used only in the first frame to generate the texture instead of inpainting for every frame to ensure consistency, and then the generated texture is overlaid on the marker area according to the camera pose. Multisensory has

been recently explored instead of the diffusion-based inpainting method for AR drawing (Meesuwan 2021). However, today, an advanced diffusion-based inpainting method has been explored for real-time inpainting 4 K color images on contemporary GPUs (Kämper and Weickert 2021).

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Live Texturing

► Live Texture Mapping in Handheld Augmented Reality Coloring Book

Localization

► Cross-cultural Game Studies
► Spatial Audio and Sound Design in the Context of Games and Multimedia

Locomotion

► Locomotion and Human Tracking in Healthcare Robots
► Navigation Artificial Intelligence

Locomotion and Human Tracking in Healthcare Robots

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Synonyms

Healthcare robots; Human tracking; Locomotion; Robot navigation; Route planning

Definition

Computer Vision	Computer vision is the Artificial Intelligence (AI) system incorporated with other scientific fields, such as signal processing and neurobiology, to interpret and gain high-level understanding from digital images or videos.
Healthcare Robot	Healthcare robot refers to a machine programmed by a computer capable of assisting humans in the medical field. In addition, it is able to provide care and support to disabled patients and the elderly.

Medicine dispenser	Medicine dispenser refers to the item that releases medications at a specific time and assists elderly persons and those who may have impaired abilities to comply with their recommended medication.

Introduction

A platform with multi-terrain navigation capabilities is necessary for a healthcare robot to move through varied geographical landscapes. The locomotion feature plays a significant role. This feature allows the robot to navigate the areas, especially inside a house with many rooms. Furthermore, another significant function in healthcare is human tracking. A healthcare robot should have both locomotion and human tracking abilities to navigate an area (e.g., a house) and look for the target person or patient when it is the right time for medication.

Motivation and Background

The World Health Organization (WHO) reported that the number of disabled persons is dramatically increasing (WHO 2011). It is related to demographic changes and a rise in chronic health problems, among other factors. Therefore, scaling up disability services in primary healthcare, particularly rehabilitation therapies, is urgently required. These disabled persons require continual supervision to complete simple tasks, such as eating and drinking. Moreover, a constant monitoring process is also necessary to avoid any emergencies. As a result, it is prudent to encourage technology that aids in detecting and responding to emergency circumstances. Many camera monitoring systems for patient behavior detection are available in the market today. However, these systems could invade in-house privacy, but they also lack the function of aiding patients. Another solution is to create mobile healthcare robots to assist the patients. Healthcare robots can track the behavior of the targeted patient. The auxiliary programs, such as time scheduling, medicine detection, and digital patient's medical record, can be integrated into the healthcare robot for enhancing its capabilities.

Beyond the conventional purview of surgical and rehabilitative robots, robots perform different activities and purposes in the medical/health and social care sectors. In this scenario, the robot may navigate to search for patients inside a specific location. However, inefficient navigation in a socio-physical environment may cause the search to be delayed, identifying emergencies. Thus, computer vision techniques can aid the navigation system in healthcare robots, such as placing the patient, evading obstacles, and detecting dangerous objects. For example, a visual-based robot navigation method for the catadioptric optical system was proposed by Winters et al. (2000). They presented a method for converting images from a catadioptric camera to bird's-eye view. These images are used to control the orientation of the robot movement. In addition, a teaching and replay approach was proposed to train the robot to navigate indoor and outdoor environments (Chen and Birchfield 2006). In the teaching phase, the robot is manually guided along the desired path, and then in the playback phase the robot follows that course independently. This method allows the robot to automatically extract the feature points along the trajectory during the training phase. The advantage of this technique is it does not require any calibration on the robot's camera. However, the change in the environment can affect the robot navigation process since the feature points are also changed.

Obstacle avoidance is another issue for mobile robots. The neuro-fuzzy technique is used to construct an intelligent obstacle-avoidance approach to autonomous navigation of a mobile robot in unfamiliar surroundings (Wang et al. 2004). The robot is integrated with four infrared sensors to detect the distance from the obstacles to the robot itself. The neuro-fuzzy model then processes this distance information to determine the optimal actions to avoid the obstacles. Estimating slip angle is also a prominent issue for wheel-based robots since there are some situations where the robots need to travel through rough terrain environments. Hough transform incorporated with fuzzy logic was applied to estimate the angle of inclination of the wheel trace with respect to the

vehicle reference frame (Reina et al. 2008). It detects the deviation in the wheel trace in real time. This deviation implies that the terrain has a change of inclination angle.

Structure of Learning System

The architecture of the locomotion and human tracking system is shown in Fig. 1.

The architecture consists of four modules: image acquisition module, vision module, decision module, and robot control module. The details are presented in the following subsections.

Image Acquisition Module

The image acquisition module controls the robot cameras. Traditionally, two cameras placed horizontally apart are used to capture two different perspectives of a scene, analogous to human binocular vision. This module synchronizes video frames from two cameras, removes noisy signals, and sends the set of digital images to the vision module.

Vision Module

The vision module is the process for extracting 3D information from the set of digital images taken from two cameras. The process is illustrated in Fig. 2.

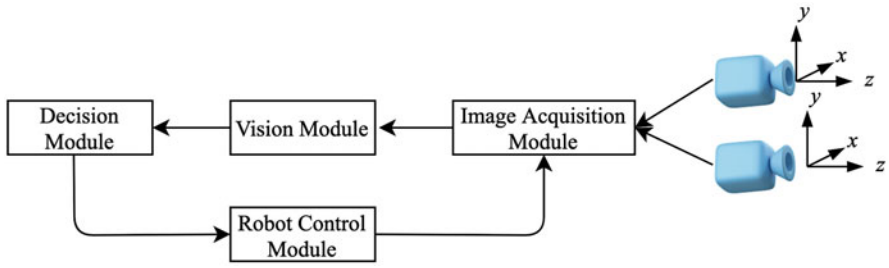
Block matching algorithm is applied to generate a disparity map that encodes the difference between corresponding picture points' horizontal coordinates from the acquired image pair (Kadri et al. 2019). The output disparity map presents the estimation of the position of features in the image pair. Then, the disparity map will be processed by a segmentation algorithm for distinguishing objects that appear in the image (Yoon et al. 2017). The disparity map segmentation image represents different objects at different distances to the robot's cameras. Next, feature extraction is applied to the disparity map segmentation to extract 2D and 3D features (Tiwari et al. 2013). These features are then used to object detection algorithms. Finally, the object detection algorithm will identify objects in the image pair (Redmon et al. 2016).

Decision Module

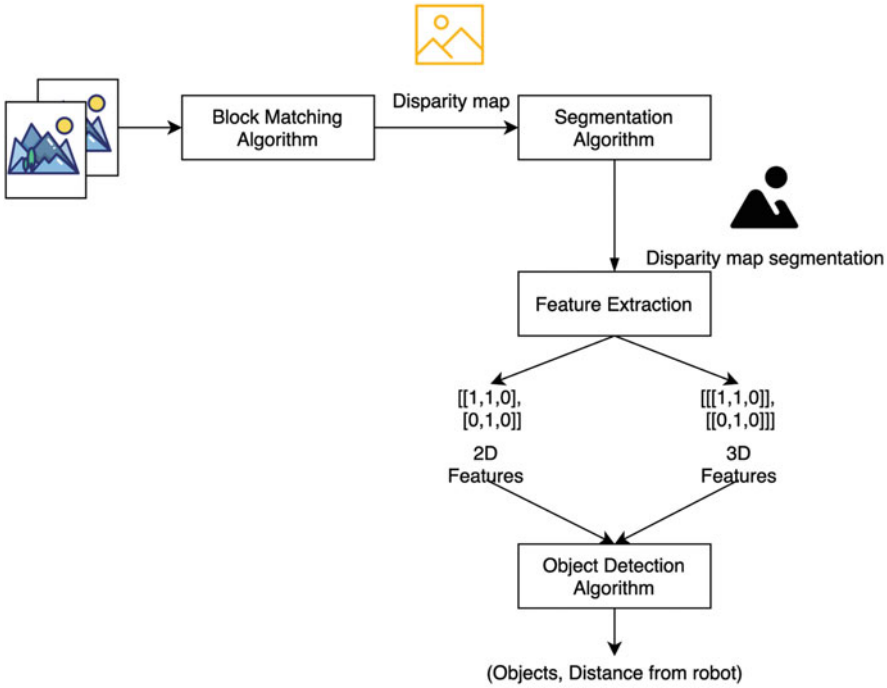
The decision module takes the information from sensors, including object information and distance from the robot, to decide which action to do next. The reinforcement learning model can be used to implement the decision module (Sutton and Barto 2018).

Robot Control Module

The robot control module controls the robot's hardware to perform the action given by the decision module. Note that the robot can contain more than one control module for various purposes (Brooks 1986). The list of control modules essential for healthcare robots are as follows:



Locomotion and Human Tracking in Healthcare Robots, Fig. 1 System architecture



Locomotion and Human Tracking in Healthcare Robots, Fig. 2 Vision module process

L

1. Cruiser module (Basu and Redi 2004)
   This module controls the robot's movement. It decides the voltage level that will be fed to the motors to control the speed and the direction.
2. Linear motion module for robot hand movement (Catalano et al. 2012)
   This module controls the simple action of the robot's arms, which are up, down, left, and right.
3. Rotation motion module for robot hand movement (Osswald and Wörn 2001)
   This module controls the complex movement of the robot's arms, which are grabbing and rotating the wrists.

Furthermore, the control modules need to be dynamic, robust, stable, and responsive since the environment varies from time to time. Finally, it should be fast enough to interact within a suitable time.

Cross-References

▶ Healthcare Robots with Islamic Practices

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Locomotion in Virtual Reality Video Games

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Synonyms

Interaction techniques; Locomotion techniques; Virtual reality systems

Definitions

Locomotion in a virtual reality video game is the travel in virtual world in order to move to a desired location.

Introduction

Most of the virtual reality (VR) systems, including virtual reality video games, often require harmoniously designed components such as audio and visual elements, task design, virtual worlds, as well as interaction and locomotion techniques. Locomotion is among the most important and very commonly used tasks in 3D virtual reality games (Bowman et al. 2004). Small position and rotation changes of the virtual viewpoint can be performed by head movements in immersive virtual reality systems that have head tracking capabilities. Such systems often use head-mounted displays to present the virtual world to the player. However, if the game requires a larger amount of travel than the real-world area, then a different locomotion technique needs to be used.

Recently in the late 2010s, many new generation, head-mounted displays became available, which are characterized as being highly immersive and affordable. HTC Vive, Oculus Rift, and Sony PlayStation VR are among the most prevalent ones of these new generation head-mounted displays. Nowadays, gamers can also use their high-end smart phones as displays for Samsung Gear VR and Google Daydream VR headsets. Although immersive virtual environments that use head-mounted displays are usually suitable for being explored on foot, there is a common major limitation of these systems. They either cannot track the position of the user's head or the position tracking is limited to a small area. One approach can be designing the virtual environment not larger than the tracked physical area and implementing a 1:1 mapping for the virtual position of the player, based on the real-world position of the user. Although there are some well-known VR game examples that use this technique, such as the game titled "Job Simulator"; this is a significantly major

limitation for game design. For VR games or applications with larger virtual environments, this 1:1 mapping technique would not work, since users will eventually go outside the real tracking space. To overcome this problem, several different locomotion techniques have been proposed in the literature. This entry reviews VR locomotion techniques that have been widely researched or used in commercial VR systems.

Virtual Reality Locomotion Techniques

Algorithm-Based Techniques

These locomotion techniques are constructed on algorithms without depending on any specific hardware. This category includes real walking (redirected walking) and gesture-based locomotion techniques (walking-in-place and flying/leaning).

Real Walking

Although it is shown to be the most presence-enhancing (Usoh et al. 1999) and less cognitively demanding (Marsh et al. 2013; Ruddle et al. 2011) locomotion technique, the real walking technique has the physical limitation of the tracking area (Whitton et al. 2005), which can make it impossible to utilize in small-sized physical spaces. In order to work around this limitation, redirected walking was introduced. Redirection can be described as altering the visual cues in virtual reality to keep the users inside the tracked area (Razzaque et al. 2001). This technique makes it possible to map large virtual environments to smaller tracked areas. In this technique, gains are applied to the locomotion data to alter user's visual cues. Keeping these gain values within the unnoticeable range is critical in order not to break user's immersion. The range for unnoticeable gain values were reported as follows: Translation −14% and 26%; Rotation −20% and 49%; and Curvature Radius 22 m (Steinicke et al. 2008, 2009, 2010). Although the virtual viewpoint of the user is altered, they can still reach to the edge of the physical tracked area. For such cases, accompanying methods were developed such as "Freeze Backup," "Freeze-Turn," "2:1-Turn" (Williams et al. 2007), and "virtual distracters" (Kohli et al. 2005; Peck et al. 2010). The aim of these accompanying methods is to make the user walk towards the center of the tracked area.

Another approach that aimed to enable real walking in virtual environments was known as "environment change." In this approach, the virtual environment's architecture was changed according to the user's navigation. In one technique, orientation of virtual doors was changed (Suma et al. 2011). In another technique, self-overlapping virtual spaces were used, which were referred to as "impossible spaces" (Suma et al. 2012) and "flexible spaces" (Vasylevska et al. 2013). In parallel lines, some portal door techniques emerged to minimize the need for real walking: "Arch-Explore" (Bruder et al. 2009) and barrier tape (Freitag et al. 2014).

Gesture-Based Techniques

These techniques aim to utilize body gestures, instead of making users really walk. Walking-in-place, flying, and leaning are among the most commonly used ones. In walking-in-place, users perform marching gesture but do not actually move in any direction in real-world (Slater et al. 1995a, b). Important attributes of walking-in-place method are as follows: step detection gesture (Feasel et al. 2008; Nilsson et al. 2013a, b; Templeman et al. 1999; Terziman et al. 2010; Wendt et al. 2010); step detection device (Feasel et al. 2008; Kim et al. 2012; Wendt et al. 2010; Williams et al. 2011; Zielinski et al. 2011); start and stop latency (Feasel et al. 2008); smooth speed control (Whitton and Peck 2013); visual gain range, which was reported as 1.65–2.44 (Nilsson et al. 2014).

Another gesture-based locomotion technique which have been commonly used in VR is flying (Guy et al. 2015; Robinett and Holloway 1992; Ware and Osborne 1990). In this flying method, user automatically moves the virtual view through some gestures. This technique offers easy implementation and ease of use; however, it was reported to be less realistic and less presence-enhancing as compared to other locomotion techniques (Usoh et al. 1999). The main issues

associated with flying were low degree of control in speed and low resemblance to real life walking interaction. A similar locomotion technique is leaning, in which users utilize their torso to control speed and rotation of locomotion. Different methods or tools have been utilized for detecting shifts in body weight such as "Nintendo Wii Balance Board" (Valkov et al. 2010) and "Human Joystick" (Harris et al. 2014). Leaning method was reported to provide higher degree of control; however, it requires more balance and body control skills. A recently popularized VR locomotion technique is referred as "Point and Teleport" that enables users to point to a place and instantly get teleported there (Bozgeyikli et al. 2016).

Tool-Based Techniques

These locomotion techniques rely on tools that give accurate position and rotation data. These tools can be stationary (walkers and standard controllers) or mobile (wearables and robots).

Stationary Tools

Stationary tools are fixed to a surface, which is usually the ground, and users climb on them for locomotion. They can work with physical effort exerted by user or through a triggering method. Physical exercise tools such as treadmills and stationary bicycles have been used for VR locomotion (Brooks 1987). In this approach, user wears a head-mounted display and uses these tools for moving in the virtual world. In the recent years, several different treadmills have been utilized for VR locomotion: unicycle; unidirectional and omnidirectional treadmills (Darken et al. 1997; Iwata 1999a, b); torus design-based treadmill (Schwaiger et al. 2007; Souman et al. 2008); low-friction surface (Jiung-Yao 2003; Suryajaya et al. 2009), ball bearings and belt combination referred to as "CyberCarpet" (De Luca et al. 2013).

Another type of stationary locomotion tools is standard controllers. Among the most commonly used ones are joysticks, joypads, and keyboards. It was reported that standard controllers are the most prevalent VR locomotion devices (Darken and Sibert 1996; Zhixin and Lindeman 2015). Main advantages are affordability in terms of price, simplicity, and familiarity from real-life experiences. Some studies resulted in findings of joystick providing better user experience in terms of locomotion as compared to other techniques (Cirio et al. 2009; Nabiyouni et al. 2015), whereas other studies reported findings that indicate joystick provided worse user experience in terms of locomotion (Peck et al. 2011, 2012; Riecke et al. 2010; Ruddle and Lessels 2006; Whitton et al. 2005).

Mobile Tools

Mobile tools are those that can be worn on user's body or moved around. Due to their complex nature, these tools are not widely available for typical consumers; however, these have been utilized in some experimental studies. For virtual reality locomotion, wearable tools such as "Cyber Boots" that included pressure foot sensors (Insook and Ricci 1997); "Waraji" that included a sandal with rotary sensors (Barrera et al. 2004); a shoe with six pressure sensors (Matthies et al. 2013); and "Powered Shoes" that included roller skates (Iwata et al. 2006) are used. In an experimental study referred to as "CirculaFloor," mobile robots were utilized as locomotion tools on which users could freely walk while not actually moving in any direction in the real-world (Iwata et al. 2005). As a drawback, all of these mobile tools require body-movement coordination and balancing skills from user's end.

Conclusion

Locomotion is an important part of virtual reality systems that may affect many factors related to user experience. Although there are several locomotion techniques that have been widely used in VR, each has its limitations or drawbacks. There is still need for exploration and improvement in this area. The introduction of the new generation VR devices in late 2010s can make it easier to explore locomotion and make it possible to introduce new locomotion ideas.

Cross-References

- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology

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Locomotion Techniques

► Locomotion in Virtual Reality Video Games

Loot Box

► Counter-Strike Global Offensive, an Analysis

Loot Boxes: Gambling-Like Mechanics in Video Games

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Synonyms

Blind bags; Blind boxes; Booster packs; Gachas; Gatchas; Loot crates; Prize crates; Random reward mechanisms; Randomized monetization methods; Surprise mechanics; Virtual Gashapons

Definition

Loot boxes are mechanics often found in video games that provide the player with randomized virtual rewards. Some loot boxes can be paid for with real-world money and therefore share structural and psychological similarities with gambling.

Introduction

"Loot boxes" is a colloquial catch-all terminology used to describe software features, typically found in video games, that provide the player with randomized virtual rewards (Drummond and Sauer 2018). The player must satisfy an "eligibility condition" to engage with (or "open") the loot box: This could be by defeating a certain in-game enemy, by obtaining a certain virtual item, by watching embedded commercials, or (more importantly) through purchasing using fiat currency (or real-world money) (Nielsen and Grabarczyk 2019). Once the player engages with the loot box, a "random procedure," of potentially varying degrees of complexity (Ballou et al. 2020), is used to determine what virtual rewards the player will obtain. The virtual "rewards" that the player obtains may be merely cosmetic items that, e.g., change the color of the player's armor, or may, alternatively, influence gameplay more significantly by, e.g., unlocking additional game content or increasing the player's in-game power (Xiao 2021). These "rewards" may be transferable (or "sold") to other players, in exchange for real-world money (Drummond et al. 2020b), or may be restricted by the video game company for use only inside the in-game economy by the original player who engaged with the loot box (Xiao 2020a). The act of engaging with a loot box may be represented in-game as the player literally opening a box containing loot; however, the loot box mechanic can also be visually represented in other forms, e.g., as tearing open a card pack, spinning a prize wheel, or receiving a capsule from a "gacha"

Loot Boxes: Gambling-Like Mechanics in Video Games, Table 1 Four categories of loot boxes proposed by Nielsen and Grabarczyk (2019)

Category	Description	Regulatory positions
Embedded-Embedded	**Costs** real-world money to engage, and its reward **does** have real-world value	**Regulated** as gambling in Belgium (Belgische Kansspelcommissie [Belgian Gaming Commission] 2018), the Netherlands (Kansspelautoriteit [The Netherlands Gambling Authority] 2018), the UK (UK Gambling Commission 2017), and most other countries that regulate gambling as a licensable activity **Banned** as gambling in most countries that more heavily prohibit gambling
Embedded-Isolated	**Costs** real-world money to engage, but its reward **does not** have real-world value	**Regulated** as gambling in Belgium (Belgische Kansspelcommissie [Belgian Gaming Commission] 2018) **Unregulated** in most other countries
Isolated-Embedded	**Does not** cost real-world money to engage, but its reward **does** have real-world value	**Unregulated** in most countries
Isolated-Isolated	**Does not** cost real-world money to engage, and its reward **does not** have real-world value	**Unregulated** in most countries

vending machine. Regardless of their visual representation, all loot boxes share the structural characteristics of being triggered by satisfying an "eligibility condition," involve a "random procedure," and provide "rewards," as described above.

Nielsen and Grabarczyk (2019) proposed a framework for classifying various implementations of loot boxes into four categories which focuses on whether the "eligibility condition" requires spending real-world money to satisfy, and whether the "rewards" can be transferred to other players in exchange for legal tender, and therefore possesses real-world value, as shown in Table 1.

Paid Loot Boxes in Context

Loot boxes that players have to purchase with real-world money to engage with are implemented by companies as monetization methods in video games, known as "microtransactions," which represent an alternative, or complementary, business model to selling copies of the software or providing subscription-based services (Petrovskaya and Zendle 2020). Analysis of loot box-spending data has revealed that the loot boxes of one single game (*Counter-Strike: Global Offensive*) generated US$528,000 in 1 day in one country alone, thus hinting at the immense size of the global loot box market (Zendle et al. 2020b).

In terms of the historical context and development of loot boxes, it has been suggested that using loot boxes to monetize video games was inspired by how collectible sports cards and fantasy trading cards (e.g., *Magic: The Gathering*) are sold in blind, randomized packs in order to encourage players to buy more packs and increase revenue (Nielsen and Grabarczyk 2019; Švelch 2020; Xiao 2021). These randomized packs were designed to contain rare cards, known as "chase cards," that were less likely to be included in packs than other cards and were therefore more sought-after and monetarily valuable. The consumer was thereby encouraged to purchase more packs in order to obtain such rare "chase cards," but they would more often only obtain less valuable, duplicate cards that they already possessed when they try to "chase" rare cards.

Loot boxes are implemented in highly popular home console games, e.g., the Ultimate Team Packs in Electronic Art's *FIFA* games (Electronic Arts 2019). Presently, loot boxes are prevalent in video games, particularly on mobile platforms,

e.g., Android and iOS: In 2019, 59% of the highest-grossing iPhone games in the UK contained loot boxes, while 36% of the 50 Highest grossing PC games on Steam contained loot boxes (Zendle et al. 2020a). Compared to in the UK, which represents the Western video game market, loot boxes are significantly more prevalent in China: In 2020, 91% of the 100 highest-grossing iPhone games contained loot boxes (Xiao et al. 2021b). This reflects that video game markets in different countries may implement loot boxes to different degrees. Video games containing loot boxes are also generally given low age ratings: 95% of the highest-grossing iPhone games containing loot boxes were deemed suitable for children aged 12+ (Zendle et al. 2020a). This suggests that children are regularly exposed to loot boxes and can readily purchase them. The UK Gambling Commission's survey (2019) found that 23% of 11- to 16-year-olds reported paying real-world money for loot boxes.

Potential Harms: Links with Problem Gambling

Paid loot boxes, because of the fact that players spend real-world money to engage with them and because of their randomized nature, are structurally and psychologically similar to gambling (Drummond and Sauer 2018). This encompasses Embedded-Embedded and Embedded-Isolated loot boxes under Nielsen and Grabarczyk's categorization (2019). Further, loot box purchasing has been found to be positively correlated with problem gambling severity in more than a dozen empirical studies in Western countries (Garea et al. 2021), e.g., the USA (Zendle and Cairns 2019), Australasia (Drummond et al. 2020a), Denmark (Kristiansen and Severin 2019), and Germany (von Meduna et al. 2020). Players with higher problem gambling severity tend to spend more money purchasing loot boxes (Zendle and Cairns 2018). In Western countries, loot box spending appears to be more strongly correlated with relatively "gamified" gambling games, e.g., online slot machines, and not correlated with more traditional gambling formats, e.g., playing bingo or the lottery in person (Zendle 2020). The relationship between loot boxes and gambling may be weaker in non-Western countries where gambling is more heavily prohibited, rather than regulated as a licensable activity, e.g., China, where lottery products represent the only legally available commercial gambling opportunity (Xiao et al. 2021a). Cultural differences and legal differences in gambling product availability may affect the relationship between loot boxes and gambling and remain a direction for future research.

Further, as in gambling contexts (Deng et al. 2021; Muggleton et al. 2021), the vast majority of loot box revenue is generated by a small minority of players spending significant amounts of money (Zendle et al. 2020b). This small minority of players have been identified as generally being players with problem gambling issues, rather than players with high personal incomes, thus suggesting that video game companies may be disproportionally profiting from potentially vulnerable consumers (Close et al. 2021). Researchers have also suggested that cognitive biases that are present in gambling contexts, e.g., the gambler's fallacy and loss chasing, which lead to maladaptive gambling, may also apply to loot box purchasing behavior and lead to maladaptive loot box overspending (King and Delfabbro 2018; Nielsen and Grabarczyk 2019; Xiao 2021). Finally, it has yet to be determined whether engagement with loot boxes in childhood affects a person's risk of developing gambling problems later in life.

Regulation by Law and Industry Self-Regulation

Paid loot boxes have been the subject of regulatory scrutiny by gambling regulators and policymakers in many countries because of their similarities with gambling and because of the link between loot box purchasing and problem gambling severity (Cerulli-Harms et al. 2020). In

particular, concerns about children engaging with loot boxes have been raised because they may be more susceptible to overspending money and more in need of consumer protection measures (Wardle and Zendle 2021; Zendle et al. 2019). Different jurisdictions are regulating the various categories of loot boxes to varying extents (Xiao 2021), as shown in Table 1. Applying existing gambling law has been how loot boxes have become regulated in nearly all countries: Various countries diverge as to which of the two categories of paid loot boxes (i.e., Embedded-Embedded and Embedded-Isolated loot boxes as defined by Nielsen and Grabarczyk) constitutes gambling and is therefore regulated: Nearly all countries agree that Embedded-Embedded loot boxes constitute gambling, but only a small minority of countries (e.g., Belgium) have taken the position that Embedded-Isolated loot boxes also constitute gambling. It is rather paradoxical that randomized physical sports and trading card packs, which arguably inspired loot boxes, are generally not considered to be a form of gambling and have thereby evaded regulatory scrutiny. Such physical packs legally constitute gambling in most countries because: They are bought with real-world money; their content is randomized; and the content has real-world monetary value because it can be sold to other people. Future research should consider why such physical Embedded-Embedded loot boxes are not considered to be gambling (Zendle et al. 2021).

The simplest regulatory solution is to ban the sale of loot boxes. This has effectively been done in Belgium where all paid loot boxes have been determined to be gambling and where no gambling licenses have been granted to video game companies for the sale of loot boxes (Belgische Kansspelcommissie [Belgian Gaming Commission] 2018). This prevents Belgian players from purchasing loot boxes and thus shields them from potential harms. However, this ban in Belgium has led to the removal of many video games that rely on loot boxes to generate revenue and which can no longer be profitably operated in that country (Xiao 2021). A blanket ban does not offer players freedom to play the video games they want or to engage with loot boxes and negatively affects video game companies' commercial interests. Conversely, nonregulation would continue to expose players, including vulnerable consumers, to potential loot box harms, and is arguably inadequate and unsatisfactory because of the precautionary principle of public health (Digital, Culture, Media and Sport Committee of the House of Commons (UK) 2019), which states that the lack of scientific certainty cannot justify regulatory inaction in a situation of high potential risk. Middle ground approaches that lie between a blanket ban and nonregulation have also been proposed and adopted in certain countries, e.g., restricting loot box purchasing only when a player attempts to go above a certain maximum spending limit (Drummond et al. 2019; Xiao 2020b, 2021).

Other consumer protection measures, which have been applied in gambling contexts (Livingstone et al. 2019), have also been identified as being potentially applicable to loot boxes (King and Delfabbro 2019; Xiao and Henderson 2021). The most prominent nonrestrictive regulatory measure is the disclosure of "winning" probabilities, which reveals how likely a player is to obtain a particular reward, as implemented in *Mario Kart Tour* (2019). This would require video game companies to reveal and publish the exact probabilities of obtaining each randomized loot box reward. The video game industry has increasingly imposed this requirement as self-regulation, e.g., by Apple (Kuchera 2017), Google (Gach 2019), and the major hardware providers and game publishers (Entertainment Software Association (ESA) 2019). This measure has also been adopted as law in China (presently the only country to do so), which has led to widespread compliance; however, the prominence and accessibility of disclosure have been identified as being suboptimal (Xiao et al. 2021b). A survey of Chinese video game players found that 85% of loot box purchasers reported seeing probability disclosures (meaning that they have been reasonably widely seen by players); however, only 19% of this group reported spending less money on loot boxes as a result of seeing the disclosures (Xiao et al. 2021a). This suggests that loot box probability disclosures may be of limited effectiveness at reducing loot box spending even if

they are accessibly and prominently displayed such that all players can see them (Xiao and Newall 2021). The video game industry has been widely supportive of loot box probability disclosure as an industry self-regulatory measure aimed at ensuring consumer protection (Entertainment Software Association (ESA) 2019), but whether self-regulation is effective remains to be assessed by future research.

Loot boxes and gambling may share many structural similarities; however, they are dissimilar in at least one regard: how the company makes money. Gambling operators lose money when the player wins money, which is why gambling operators must ensure that the gambling games are designed such that the operator is more likely than the player to win. In contrast, a video game company does not directly lose money when the player wins a reward, valuable or otherwise, as it does not directly cost money to give players these virtual rewards. However, it should also be noted that a video game company would face an indirect loss when a player wins a valuable reward (Xiao 2020c): A player may stop purchasing a loot box after receiving their desired reward, meaning that the video game company may stop making money from that player after the valuable reward is given out. In order to be sustainable, many loot box systems rely on frequent updates with new rewards, but each new reward costs money for the video game company to develop, meaning that companies would have to expend more costs to develop more new content if players are able to more easily obtain desirable rewards. Further, the value and desirability of a reward would decrease if all players managed to obtain it: It would no longer be a "rare" reward with which players could impress others. However, despite the potential for indirect loss, video game companies are still financially able to give out their most valuable rewards more frequently than traditional gambling operators. This means that loot box consumer protection methods do not have to be limited to what has been done in gambling contexts, and that loot box consumers could be additionally protected by novel features of ethical game design, e.g., allowing players to win valuable rewards more often (King and Delfabbro 2019; Xiao and Henderson 2021; Xiao and Newall 2021).

Conclusion: Directions for Future Research

Loot boxes, and paid loot boxes in particular, represent a relatively novel mechanic in video games. Despite increasing research attention being paid to the issue, further research is required to fill in the existing knowledge gaps. Future correlational research between loot boxes and gambling should examine whether loot box purchasing is more strongly correlated with engagement with specific gambling products, rather than engagement with gambling in general. Existing research has largely utilized self-reported data: Transparent collaboration with the video game industry may provide more reliable data. Indeed, qualitative methods may assist in better understanding individual players' experiences with loot boxes (Nicklin et al. 2021), and gauging players' views as to the implementation and regulation of loot boxes (Petrovskaya and Zendle 2021): This is especially relevant for Embedded-Isolated loot boxes because, although this category represents the vast majority of paid loot boxes implemented in video games, these mechanics have no obvious counterparts in nondigital contexts, and therefore there is no translatable literature from other fields. Further, cross-cultural perspectives would clarify whether players in various countries are experiencing loot boxes differently. Additionally, neuroscience perspectives may shed light on how player's cognition is affected when engaging with loot boxes: Such perspectives are prominent in research on gambling disorder; however, as of yet, they are missing from the loot box literature. Finally, the prevalence of serious problems with loot box spending has never been assessed, and it is not known whether such problems are caused by exposure to loot boxes or are instead symptoms of preexisting underlying issues. In conclusion, despite recent advances made by the literature, loot boxes remain an area deserving of further research.

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Loot Crates

▶ Loot Boxes: Gambling-Like Mechanics in Video Games

Loud-speaker Reproduction

▶ Sound Spatialization

Lowest%

▶ Speedrunning in Video Games

Ludification

► Gamification

Ludii General Game System for Modeling, Analyzing, and Designing Board Games

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Definition

The Ludii computer program is a complete general game system for digitally modeling, analyzing, and designing a wide range of games. These include traditional tabletop games such as board games and dice games, in addition to card games, graph games, mathematical games, puzzles, simulations, and simple video games. Ludii supports stochastic (chance) elements, hidden information, adversarial and cooperative modes of play, and any number of players from 1 to 16.

The system differs from existing *general game playing* (GGP) programs in a number of ways. Its underlying ludemic model allows a wider range of games to be described more easily and succinctly than other approaches, and it is intended as a tool for game *design* as much as game *playing*. Ludii belongs the "hybrid" class of GGP approaches that allows extensible higher-level game descriptions (Kowalksi et al. 2020).

The Ludii distribution comes with over 1000 predefined games and a number of default *artificial intelligence* (AI) agents for playing and analyzing these, in addition to new games authored by users. An open Ludii AI API is provided to facilitate the system's use as a platform for general game-based AI research. Ludii's Java code base is freely available under a Creative Commons (CC BY-NC-ND 4.0) license.

Ludii was developed as part of the European Research Council (ERC) funded Digital Ludeme Project with one of its primary purposes being for the reconstruction of historical games from partial rulesets based upon the available evidence (Browne et al. 2019b). However, this is only one application, and Ludii provides a range of features intended to help the modern game designer prototype, fine tune, and discover new designs.

The Ludii System

The Ludii system is based on the notion of the *ludeme*, which can be described as a game related concept or element of play that is relevant to the equipment and/or rules of a game (Browne 2021). Ludemes constitute the fundamental building blocks of which games are composed.

Games are defined for Ludii as structured ludeme trees in the form of LISP-like symbolic expressions, according to a custom grammar that constitutes the *Ludii Game Description Language* (L-GDL). For example, the game Tic-Tac-Toe can be defined as follows:

```
(game "Tic-Tac-Toe"
   (players 2)
   (equipment {
      (board (square 3))
      (piece "Disc" Each)
   })
   (rules
      (play (move Add (to (sites
      Empty))))
      (end
         (if
             (if Line 3)
             (result Mover Win)
         )
      )
   )
)
```

This *ludemic model* for describing games allows a wide range of games to be described simply and succinctly. The fact that ludemes encapsulate key game concepts makes such descriptions highly conducive to automated manipulations such as the evolution of new games from existing rulesets (Browne 2009).

Architecture

Figure 1 shows an overview of the main components of the Ludii system. Additional information on the relevant modules are provided in the following sections.

The game description (written using the L-GDL) is initially passed into the Grammar module, which first expands and parses the game description to check that it is syntactically valid. Once this initial check is done, the game description is then compiled, transforming it into its internal logic format within the Core module. This internal logic contains all the relevant information about the game, including the equipment, rules, and supplementary metadata. The metadata provides additional information about the game which is not related to how it is played. This includes textual information about the game – such as its rules, author, and historical details – but also graphical information about how the game should be visualized.

The rules section of the Core module is then used by the Manager module, which is responsible for coordinating the moves of the game. This module takes input from either a human user, via the Player module, or an Agent, via the AI module.

The equipment section of the Core module is used by the ViewController module, which is responsible for constructing the relevant graphics for the containers and components used in the game (view) as well as how interface inputs should be converted into game moves (controller). Any graphical options specified in metadata are also used by the view section of the ViewController module, to supplement or override what is defined in the equipment. For example, a metadata line could be added to the game that changes the size of a piece or the color of the board.

The Player module displays the visuals provided by the ViewController module to the user. When the user interacts with these visuals, the controller converts these inputs into a logical move and sends this to the Manager module. The Player module provides different visuals and interaction handling depending on if the user is operating on their own local version of Ludii (desktop) or the remote website version (web). Once the Manager module verifies that this move is valid, it is passed to the Core module, where the state of the game is updated.

Grammar

The custom Ludii Grammar is an Extended Backus-Naur Form (EBNF) style grammar consisting of a set of production rules used to generate game descriptions. The grammar is generated automatically from the Ludii code base using a *class grammar approach* in which all keywords, rules, and instantiations are derived directly from their corresponding Java classes (Browne 2016).

This approach provides a 1:1 correspondence between the L-GDL and the underlying Java code at all times, effectively making the Ludii Grammar a snapshot of the current class hierarchy and making the system easily extensible. New functionality can be added by simply implementing the relevant Java classes, which will then be automatically incorporated into the grammar the next time that Ludii is launched.

Each game description is contained in a plain text file with *.lud extension. When a game description is loaded into the Ludii system, the following steps are performed to compile the description into an executable Game object, as shown in Fig. 1:

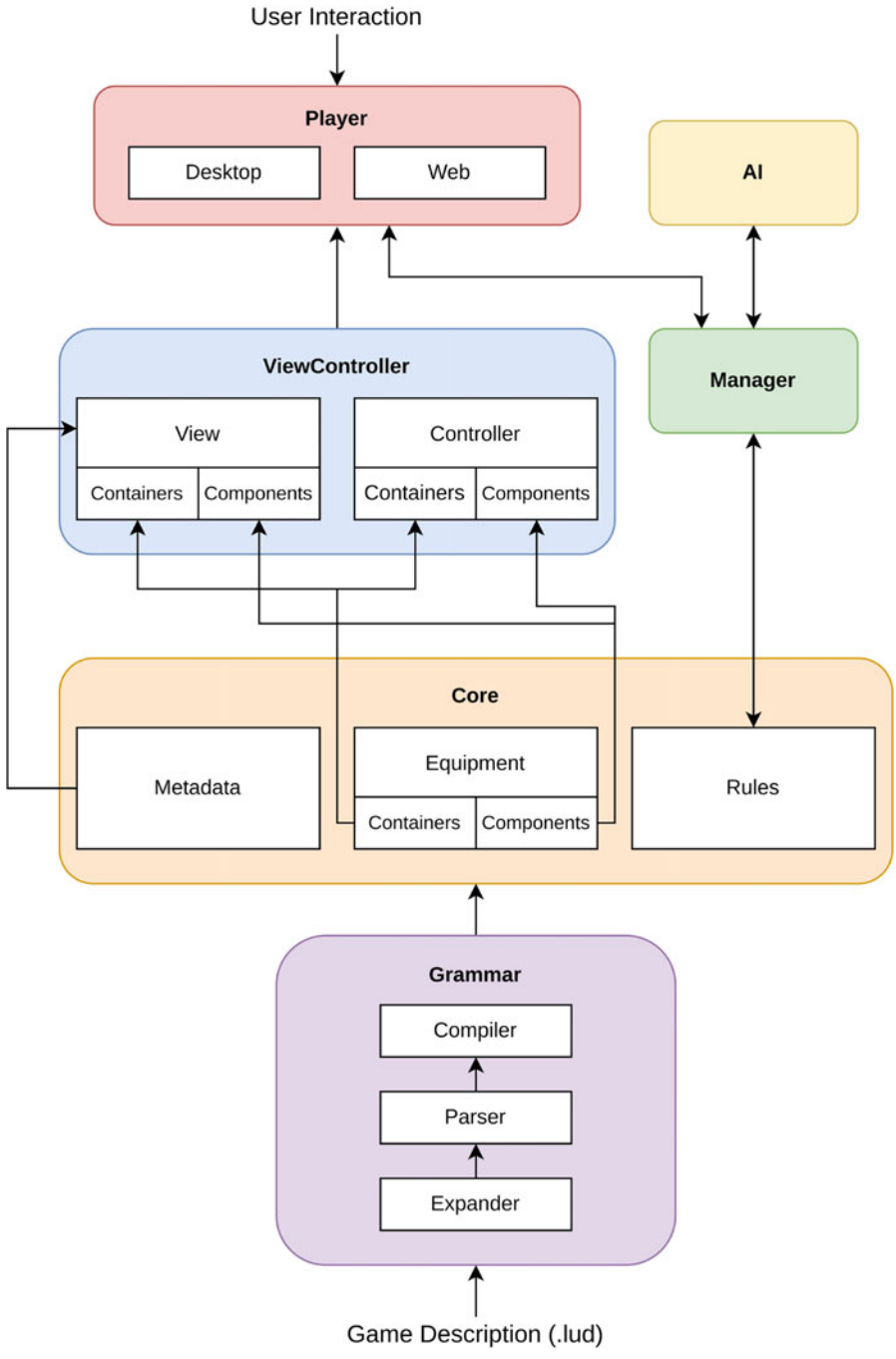
1. *Expand:* The game description is expanded into a plain text string to resolve certain metalanguage features and decorations.
2. *Parse:* The resulting string is parsed for correctness according to the current Ludii Grammar.
3. *Compile:* The Java classes corresponding to the game description keywords are recursively instantiated with the specified parameters to produce an executable Game object in Java bytecode.

Internal Model

The game representation and the transitions between states are described in the following sections.

Game Representation

A game is defined as a 4-tuple of ludemes:



Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Fig. 1 Architecture overview of the Ludii general game system

- **Players**: provides the information about the players (number of players, direction of each player, ...).
- **Mode**: corresponds to the game control and describes if the game is played alternatingly or simultaneously.

- **Equipment**: describes all the information about the containers used in the game (boards and hands) as well as the components (i.e., the game pieces).
- **Rules**: describes the initial state, how different components interact with each other, what moves can be made, and the conditions to reach a terminal state.

Figure 2 shows the components of a game in Ludii.

State Representation

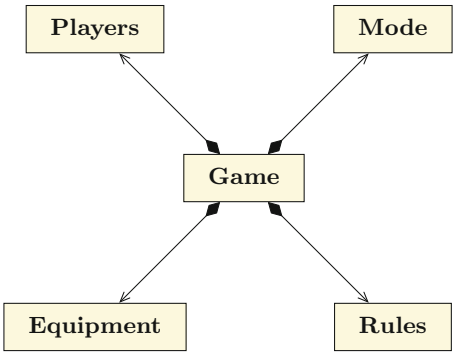
A Ludii game state s encodes which player is to move in s as well as which player was moving in the previous state and which player is going to move in the next state.

Each container of a game is modeled as a graph defined by a set of cells C, a set of vertices V, and a set of edges E. Each playable *location* $l = \langle c_i, t_i, s_i, l_i \rangle$ is specified by its container $c = \langle C, V, E \rangle$, a site type $t_i \geq$.

$\in$ {Cell, Vertex, Edge}, a site index $s_i \geq 0$, and a *level* $l_i \geq 0$. Every location specifies a type of site in a specific container at a specific level. Each container of the game has its state representation called container state.

A container state cs is implemented as a collection of data vectors for each playable site. The different data vectors are:

- what[l]: The index of the component at l, or 0 if there is no component.
- who[l]: The index of the owner of the component at l, or 0 if there is no component.
- count[l]: The number components (of a single type) at l.
- state[l]: The local state of the component at l, or 0 if there is no component.
- value[l]: The value of the component at l, or 0 if there is no component.
- rotation[l]: The rotation index of the component at l, or 0 if there is no component.



Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Fig. 2 The game components

Different representations are implemented to minimize the memory footprint and to optimize the time needed to access necessary data for reasoning on any game. These representations are:

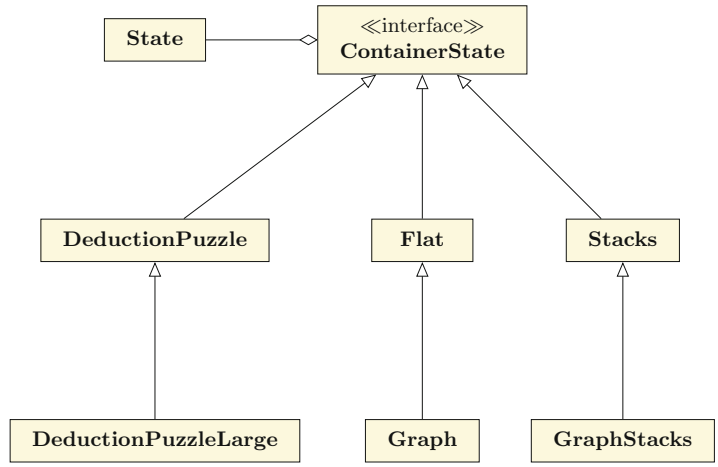
- Flat state: For games played on one single site type without stacking.
- Graph state: For games played on multiple site types without stacking.
- Stack state: For stacking games played on one single site type.
- Graph Stack state: For stacking games played on multiple site types.
- Deduction Puzzle state: For puzzles corresponding to a Constraint Satisfaction Problem (Piette et al. 2019).

Figure 3 shows the relations between the different state representations. Thanks to these different state representations, Ludii is able to model a very large set of various games. Figure 4 shows an overview of the Ludii games library (1019 games in version 1.3.0).

Trial and State Transitions

A Ludii successor function is given by $\mathcal{T}$: $(\mathcal{S} \backslash S_{\text{ter}}) \times \mathcal{A} \mapsto S$, where $\mathcal{S}$ 6is the set of all the Ludii game states, S_{ter} the set of all the terminal states, and A the set of all possible lists of actions, where a single list of actions is a move that a player can select. Given a current state $s \in \mathcal{S} \backslash S_{ter}$, and a list of atomic actions $A = [a_i] \in \mathcal{A}$, $\mathcal{T}$ computes a successor state $s' \in \mathcal{S}$.

A trial τ is a sequence of states s_i and action lists $A_i : s_0, A_1, s_1, \ldots, s_{f-1}, A_f, s_f$ such that $f \geq 0$, and for all $i \in \{1, \ldots, f\}$,



Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Fig. 3 The different state representations

Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Fig. 4 Some example visualizations of games from the Ludii Library

- The played action list A_i is legal for the mover (s_{i-1}).
- States are updated: $s_i = \mathcal{T}(s_{i-1}, A_i)$.
- Only s_f may be terminal: $\{s_0, \ldots, s_{f-1}\} \cap \mathcal{S}_{ter} = \emptyset$.

When a new state s_{i+1} is reached after applying A_i selected from the list of legal moves for a state s_i, Ludii computes the new list of legal moves of s_{i+1} and stores them in the trial for any caller to access them quickly without needing to compute them again.

A trial is over when all players are inactive and associated with a rank. The outcome of the game corresponds to the ranking of the players.

In short, a trial τ provides a complete record of a game played from start to end, including all the moves made stored in a list. Any reasoning on any

game can be parallelized using separate trials per thread. All the data members of a game are constant and can therefore be shared between threads. A thread will be able to use a trial τ to compute any playout from any state.

In Ludii, a single object called *Context* is used to store references to the game, the state representation s, and the trial τ. For any operation such as computing the graph of a container, computing the initial state s_0, or computing the legal moves for a state s, Ludii evaluates a tree of ludemes by calling a method eval(context) to evaluate it according to the current state. The *Context* also contains the random number generator used for any stochastic operations in the corresponding trial and the value of the model – alternating or simultaneous – used to apply moves or compute the legal moves in a specific game state. Alternating-move models expect only a single player to select a move at a time, whereas simultaneous-move models expect *all* active players to select a move at every time step, and simulations simply apply all legal moves automatically. More details about the internal model can be found in Piette et al. (2021).

Board Representation

In Ludii, the board shared by all players is represented internally as a finite graph defined by a triple of sets $\mathcal{G} = \langle V, E, C \rangle$ in which V is a set of *vertices*, E a set of *edges*, and C a set of *cells*.

For example, Fig. 5a shows a game with pieces played on the vertices, edges, and cells of the board graph. Figure 5b shows a board game played only on the cells but in which pieces may stack.

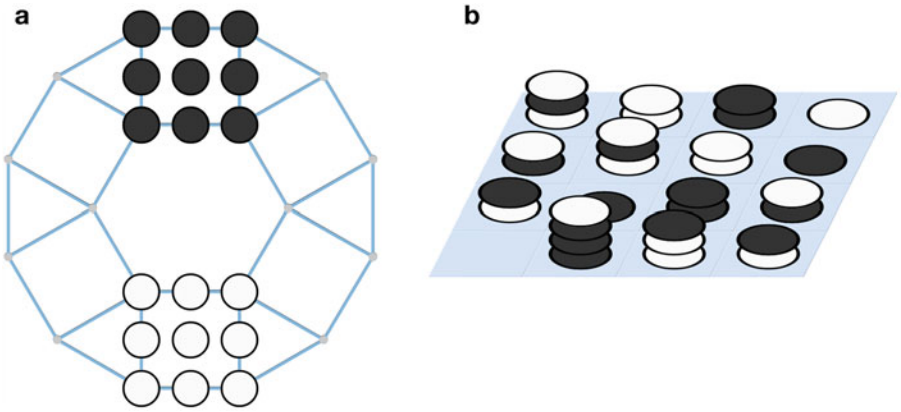
In any given game, a component (or a stack of components) can be placed on any location corresponding to a graph element and a level.

Two different graph elements can have different relations: Adjacent, Orthogonal, Diagonal, Off Diagonal, or All. The complete definition of each of these relations is provided in Browne et al. (2021). These relationships are summarized for the regular tilings in Table 1.

Ludii supports the following direction types:

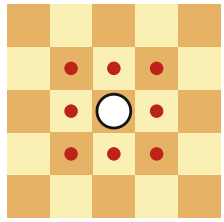
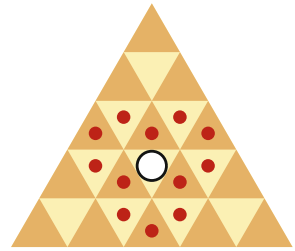
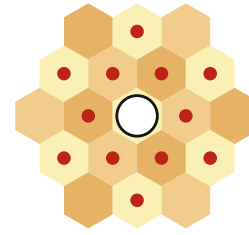
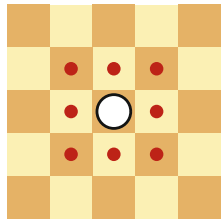
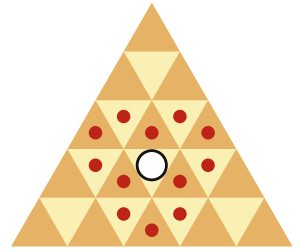
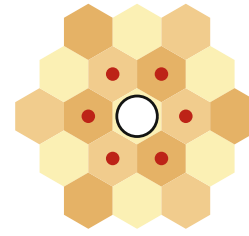
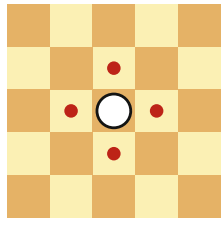
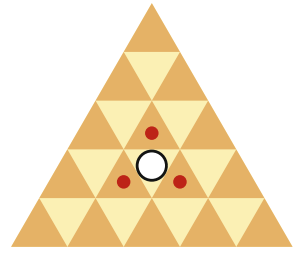
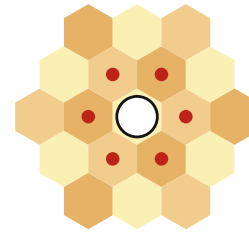
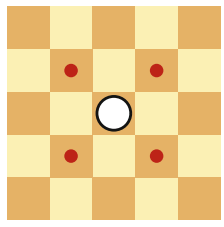
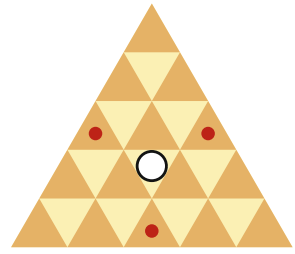
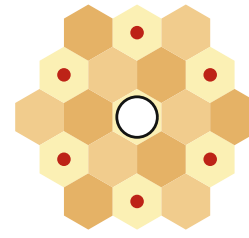
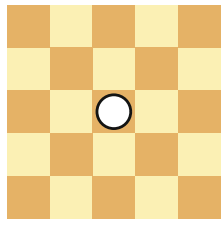
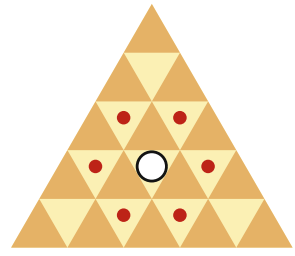
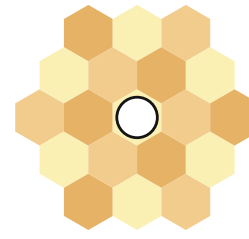
- *Intercardinal* directions: `N`, `NNE`, `NE`, `ENE`, `E`, `ESE`, `SE`, `SSE`, `S`, `SSW`, `SW`, `WSW`, `W`, `WNW`, `NW`, and `NNW`.
- *Rotational* directions: `In`, `Out`, `CW` (clockwise), and `CCW` (counterclockwise).
- *Spatial* directions for 3D games: `D`, `DN`, `DNE`, `DE`, `DSE`, `DS`, `DSW`, `DW`, `DNW` and `U`, `UN`, `UNE`, `UE`, `USE`, `US`, `USW`, `UW`, and `UNW`.
- *Axial* directions subset (for convenience): `N`, `E`, `S`, and `W`.
- *Angled* directions subset (for convenience): `NE`, `SE`, `SW`, and `NW`.

Each graph element has a corresponding set of *absolute directions* and *relative*



Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Fig. 5 A game played on vertices, edges, and cells (**a**) and a game played only on cells (**b**)

Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Table 1 Relations for the regular tilings

Relation	Square	Triangular	Hexagonal
All			
Adjacent			
Orthogonal			
Diagonal			
Off-Diagonal			

directions to associated graph elements of the same type. Absolute directions can be any of the above direction types in addition to any relation type (`Adjacent`, `Orthogonal`, `Diagonal`, `Off Diagonal`, or `All`).

Relative directions from an element are defined by the direction in which a component is facing, the number of rightward steps of the component, and the graph relation to use at each step (Adjacent by default). Relative directions are: `Forward`, `Backward`, `Rightward`, `Leftward`, `FR`, `FRR`, `FRRR`, `FL`, `FLL`, `FLLL`, `BR`, `BRR`, `BRRR`, `BL`, `BLL`, or `BLLL`.

Game Logic

The logic of an L-GDL game (Piette et al. 2021) is computed from its *rules*, ludeme which is defined by the following ludemes which correspond to different rule types:

1. *meta*,
2. *start*,
3. *play*,
4. *end*.

For example, the following L-GDL code describes the Game of the Amazons (Amazons: ludii.games/details.php?keyword = Amazons) with an additional swap rule (a rule that allows the second player to swap colors after the first move to reduce any first move advantage). This game is used as example in the next sections.

```
(game "Amazons"
   (players 2)
   (equipment {
      (board (square 10))
      (piece "Queen" Each
       (move Slide (then (moveAgain)))
      )
      (piece "Dot" Neutral)
   })
   (rules
      (meta (swap))
      (start {
        (place "Queen1"
        {"A4" "D1" "G1" "J4"}
         )
        (place "Queen2"
          {"A7" "D10" "G10" "J7"}
        )
      })
      (play
        (if (is Even (count Moves))
          (forEach Piece)
          (move Shoot (piece "Dot0"))
        )
      )
      (end
        (if
          (no Moves Next)
          (result Mover Win)
        )
      )
   )
)
```

Metarules

In Ludii, a metarule, defined with the ludeme *meta*, is a global rule applied in each state s reached after applying the move decided by the player. That rule can modify the state s or can add/remove some moves from the list of legal moves. In the Game of the Amazons, the swap rule is defined using the metarule (*swap*) (line 12). Here, after the first player has finished their turn, the second player has one more legal move allowing them to swap with the other player. The metarules are optional.

Starting Rules and Initial State

When a game is creating after being compiled, the state s_{-1} corresponds to all the variables set to their default values and no piece placed in any playable location. The starting rules (lines 13–20) of the Game of the Amazons are used to place the queens on the expected locations to create the initial state. These rules define a list of movements A_0 applied to the state s_{-1} to build s_0. The starting rules are optional.

Playing Rules and Move Generation

The playing rules of a game describe how to generate the legal moves of the mover for any current state s_i. These legal moves are defined in the Play ludeme through its Moves ludemes. The playing rules of the Game of the Amazons are described in lines 21–26.

At each state s_i, the Moves ludeme used to describe the playing rules are evaluated according to the state and return a list of k legal moves $\mathcal{M} : \langle m_1, \ldots, m_i, \ldots, m_k \rangle$ stored in the trial τ. As described in Section, the transition between two successive states s_i and s_{i+1} is possible as a sequence of atomic actions A_i applied to s_i. Such a

sequence is modeled as a move $m : \langle a_1, \ldots, a_i, \ldots, a_n \rangle$, where n is the number of actions in A_i..

An atomic action a is the only operator able to modify the state after its creation. Consequently, when a player selects their move m from the list of legal moves available in the trial for the state s_i, this state is updated by applying successively each atomic action in the list of actions composing the move m.

Ending Rules and Terminal States

The ending rules describe when and how play can terminate for one or more of the players. In the Game of the Amazons, the ending rule (lines 27–32) checks whether the next player has no legal moves; if this is the case, the game is over and the current player wins.

In Ludii, any conditions to reach an ending state are described in the ending rules, followed by the description of the outcome of at least one player. In games with two players or fewer, an ending rule describes a terminal state s_{ter}, but for games with more players, the game can continue if play did not yet terminate for at least two of the players.

Functions

All the ludemes defining the rules are functions that are evaluated according to a state s returning a specific type of data. Five types of functions exist in Ludii:

- **Moves** functions return a list of moves. The Moves ludemes starting by (move ...) describes a decision move, all the other Moves ludemes are effect moves. To make the computation of the legal moves efficient, the effect moves which have to be applied before the decision action a_d are distinguished from those that have to be applied after, corresponding to the consequences of the decision and described using the ludeme (then ...). Due to that distinction, only the non-consequence moves are fully evaluated during the computation of the legal moves, and the consequences are evaluated only when a specific move has been selected to be applied by the player. In the context of the slide movement of the Game of Amazons, the effect Moves ludeme (moveAgain) is evaluated when a slide move is decided, setting the next player be the current mover.
- **Arithmetic** functions return one or many numerical values. The arithmetic functions are composed of many different functions according to the type of numerical values returned (array, integer, range, or real). As examples, the ludemes (count Sites "Board") and (count Players) return the number of sites in the board, and the number of players, respectively.
- **Logic** functions return a Boolean value. The most common logic functions start by (is ...), such as (is Even (count Moves)), which returns true if the number of moves played so far is even.
- **Region** functions return one or many playable sites. The most common region functions start by (sites ...), such as (sites Board), which returns a list of all the sites on the board.
- **Direction** functions return one or many absolute directions. For example, (directions {Rightward, Leftward}) is returning the absolute directions corresponding to the right and left of the current direction of a piece.

Ludii Player

The Ludii Player provides the graphical user interface (GUI) aspect of Ludii. This includes both the visuals and controls for playing games, as well as additional software options to improve the user/developer experience (e.g., remote online games, a built-in editor, game analysis tools, advanced graphical settings, etc.). This is something that is either missing or severely lacking in most other general game systems.

An example screenshot of the main Ludii Player GUI is shown in Fig. 1. This example demonstrates an in progress game of Shogi. The left side of the player shows the current state of the game board. The top right area of the player displays details about each player, including who is controlling them and the contents of their hand. The bottom right area provides supplementary information about the game, such as the moves that have been made, ludeme description, agent analysis results, etc. A range of menu options at

the top of the Ludii Player also provides many other alternative features.

A few of the user-friendly features offered by the Ludii Player, and their uses for research, are now described. Firstly, being able to visually see and play the games described using the L-GDL makes testing and verifying the correctness of game descriptions much easier. The benefit of this point should not be understated, as there have been several cases of games being described for alternative systems which were later found to be incorrect. Secondly, the heuristics and strategies of agents can be easily viewed to see their current performance and if there are any obvious weaknesses in their behavior. Humans can also play directly against agents to help determine if they are at a human-level playing strength. Lastly, providing a user-friendly interface is more inviting to the general public and encourages other game design enthusiasts to create their own games, leading to a larger range of games for research purposes. Ludii currently includes over 1000 games which were created by members of the general public, with new games being added frequently.

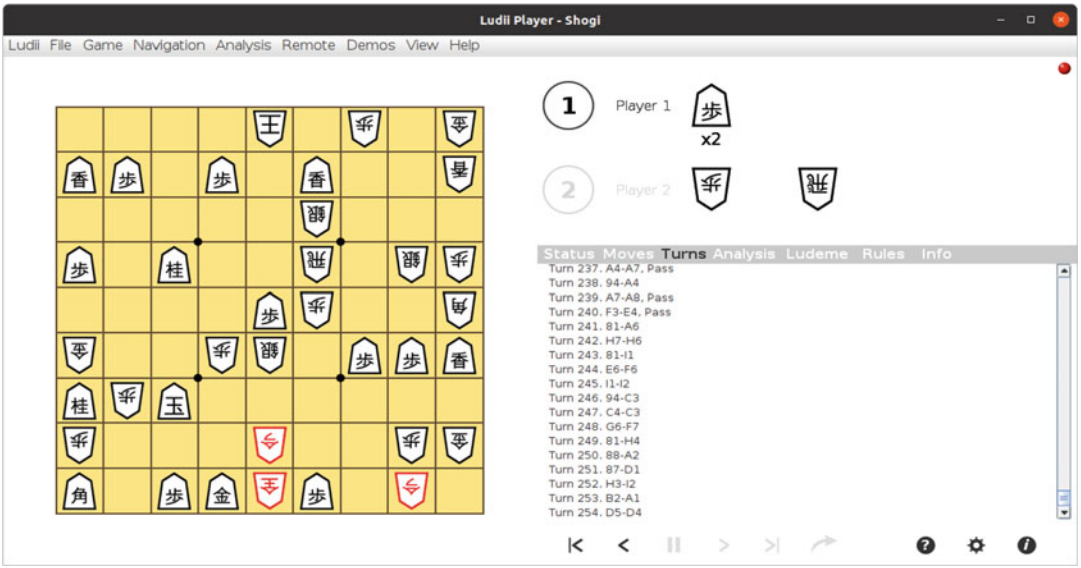
User Interface

The Ludii Player provides the graphical user interface (GUI) aspect of Ludii, including both the visuals and controls for playing games. There are currently two different version of the Ludii Player: the Desktop Player, which is used when running Ludii locally on any standard PC, and the Web Player, which is used when interacting via the Ludii Portal Website.

Ludii Desktop Player

An example screenshot of the Ludii Desktop Player GUI is shown in Fig. 6. The left side of the player shows the current state of the game board. The top right area of the player displays details about each player, including who is controlling them and the contents of their hand. The bottom right area provides supplementary information about the game, such as the moves that have been made, ludeme description, agent analysis results, etc. A range of menu options at the top of the Ludii Desktop Player also provides many other additional features, including but not limited to:

- The ability to play remote games and tournaments with other Ludii users online.



Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Fig. 6 The graphical user interface (GUI) of the Ludii Desktop Player for an in progress game of Shogi

- A built-in editor for creating, modifying, and saving Ludii game descriptions.
- Game analysis tools for evaluating and comparing games across a variety of metrics.
- Multiple graphical settings, such as animations, move highlighting, cell coordinates, etc.
- The ability to select different game options and rule sets.

Ludii Web Player

An example screenshot of the Ludii Web Player GUI is shown in Fig. 7. This picture was taken from a mobile smartphone device in portrait mode. Other devices may arrange certain elements such as the player hands differently, but are otherwise functionally identical. As can be seen, the Web Player contains less features that the Desktop Player, essentially only allowing the user to play the game against other AI or human opponents. The benefit of the web version, however, is that it can be played on almost any device with an internet connection and does not require the user to install Java beforehand.

Ludii Portal

Both the Ludii Web Player and the download link for the Ludii Desktop Player can be accessed via the Ludii Portal (ludii.games). This portal also provides additional information about Ludii and the games within it. Some of main web pages that can be accessed from this portal include:

- The Ludii Game Library (ludii.games/library), which displays images and category information for all games within Ludii. Selecting a game from this library will open a Web Player instance of that game.
- The Ludii Downloads Page (ludii.games/download), which contains links for downloading the Ludii Desktop Player, as well as other Ludii documentation.

Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Fig. 7 Ludii Web Player GUI for mobile devices, showing Chess

- The Game Concepts Search Page (ludii.games/searchConcepts), which can be used to search for games with a specific combination of over 700 defined concepts.
- The Ludeme Tree Page (ludii.games/ludemeTree), which displays an interactive hierarchy tree for all the ludemes within the L-GDL.

Artificial Intelligence

Ludii provides an API for game-playing agents using any artificial intelligence (AI) techniques to be developed and used to play any of Ludii's games from within its GUI-based player as well as command-line programs and competitions (Stephenson et al. 2019). The API for agents provides them with a *forward model*; given any (current) game state, this may be used to generate lists of legal moves, generate successor states resulting from the application of moves, query whether or not a game state is terminal or any rankings have already been determined, and so on. This is similar to the API provided by the General Video Game AI (GVGAI) framework (Perez-Liebana et al. 2019) for its collection of video games. This interface is sufficient for typical tree search algorithms as commonly used for GGP, such as Monte-Carlo Tree Search (MCTS) (Kocsis and Szepesvári 2006; Browne et al. 2012; Coulom 2007). There is also support for tensor representations of states and actions to be generated, the use of which has been demonstrated in a bridge between Ludii and the Polygames (Cazenave et al. 2020) framework of deep learning approaches for games. Various types of constraints can be specified for agents, such as processing time per move, maximum iteration count, and maximum search depth; different constraints may be more or less suitable for different experiments or use cases.

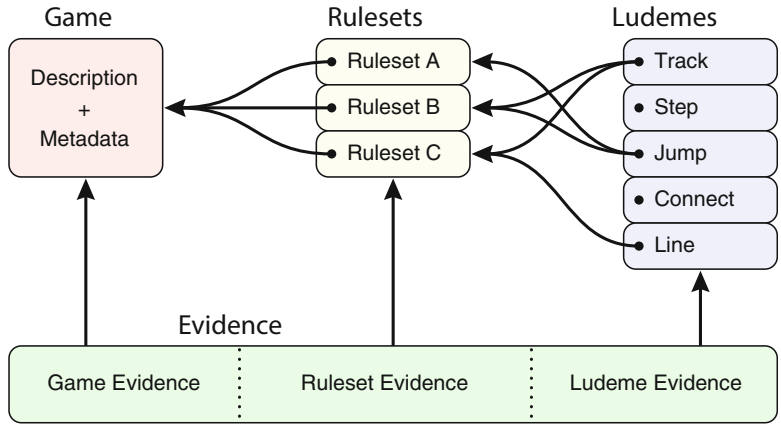
Based on this interface, several standard algorithms have already been implemented and included directly in Ludii, as well as new techniques developed and proposed specifically in the context of DLP and Ludii. In GGP, one of the most commonly used search algorithms is MCTS. Ludii includes implementations of several variants and common extensions, such as UCT (Browne et al. 2012), GRAVE (Cazenave 2015), MAST (Finnsson and Björnsson 2008), Progressive History (Nijssen and Winands 2011), and NST (Tak et al. 2012). It also includes training techniques and variants of MCTS that are guided by trained features, which are described in other publications (Browne et al. 2019a; Soemers et al. 2020).

Another search technique implemented in Ludii is $\alpha\beta$-search (Knuth and Moore 1975), with Max^N (Luckhardt and Irani 1986), Paranoid search (Sturtevant and Korf 2000), and BRS+ (Esser et al. 2014) extensions for games with more than two players. Unlike MCTS, these techniques require heuristic evaluation functions – generally based on domain knowledge – to compare the "desirability" of various states. A variety of heuristics, most of which were found to be fairly generally useful across multiple games (Browne 2009), are included in Ludii for this purpose. Typical examples include a *material* heuristic to count weighted sums of types of pieces owned by players or terms that compute proximity to board centers, corners, sides, and so on.

Ludii Database

All relevant information about each official Ludii game (i.e., those which are included within the code Ludii software and repository) is stored inside the Ludii Game Database (LGD). This data can be decomposed into two main types, *game-related* and *evidence-related*. The evidence-related data is primarily stored only for games that are relevant to the goals of the DLP. As such, a large portion of games in the LGD does not have any evidence-related information. As this information is unlikely to be useful outside of this archaeological context, this section will focus primarily on the game-related data. This game-related data can further be split into three subsections: *games*, *rulesets*, and *ludemes*. Each game can be thought of as being composed of one or more rulesets, with each rulesets being made up of multiple ludemes.

While the distinction between a game and a ruleset is not exact, two sets of rules/equipment can be considered different games if they come from different places or existed in different time



Ludii General Game System for Modeling, Analyzing, and Designing Board Games, Fig. 8 Overview of the main Ludii Game Database groups and their relationships

periods. If they cannot be separated, however, then they are considered different rulesets of the same base game. This can lead to two rulesets of the same game with very different rules/equipment, such as two different sets of rules that have been suggested for a historical game with largely unknown rules. It can also lead to two distinct games with very similar rules/equipment, to consider the possibility that these games were created independently in different places and times.

A rough outline of the LGD structure is shown in Fig. 8.

Games

Each game entry in the LGD describes a specific game (i.e., a single .lud game description) in Ludii. Each of these game entries will also have at least one ruleset associated with it, although it can have more. Auxiliary metadata information about each game is also stored, such as plain English descriptions of the game and its rules, any aliases, publication details, and so on.

Rulesets

A ruleset is a defined set of ludemes which describe the specific rules and equipment that is used to play a certain game. These rulesets could be speculative in nature or can simply be a known variant of an established game (e.g., the different scoring systems for the game Go). Playing the same game with a different ruleset can often lead to different gameplay experiences. One ruleset could make a game long and biased, with little room for strategic play while another could provide the complete opposite. As a result of this change, it is these rulesets that are evaluated and analyzed when it comes to gameplay, rather than the game itself.

Ludemes

A ludeme is single elemental building block of a game. Multiple ludemes can be combined together to create a description of a specific piece of equipment or rule that a game uses. Each ludeme is stored in the LGD and is associated with the rulesets which use it. If a game has any ruleset that uses a particular ludeme, then by extension, that game will also be considered as using that ludeme.

Cross-References

▶ Monte-Carlo Tree Search

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Ludo Game

► Augmented Reality Ludo Board Game with Q-Learning on Handheld

Ludonarrative

► Narrative in Video Games

Ludosemiotics

► Semiotics of Computer Games

M

Machine Intelligence

▶ Computer Games and Artificial Intelligence

Machine Learning

▶ Audio and Facial Recognition CAPTCHAs for Visually Impaired Users
▶ Classical Learning Method in Digital Games
▶ Fall Risk Detection in Computer Vision
▶ Human Interaction in Machine Learning (ML) for Healthcare

Machine Learning for Computer Games

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Synonyms

Clustering; Deep learning; Game AI; Hidden Markov Models; Learning agents; Nearest neighbors; Neural networks; Regression; Reinforcement learning

Definitions

Video game modding: It is the process of modification of a video game by players or fans, for changing the gaming experience by allowing others to get and use these modifications, which are referred to as "mods."

Ensemble learning: Use of multiple learning algorithms to obtain better performance than that obtained by using any of these algorithms in isolation

Transfer learning: It is the process of reusing knowledge from previously learned *source tasks* to bootstrap learning of target tasks (Braylan et al. 2016).

Introduction

There are multiple ways in which some or all of the research at the intersection of machine learning and computer games can be surveyed. One can survey the applications of one machine-learning paradigm in computer games in one genre. One can survey the applications of multiple machine-learning paradigms in computer games in one genre. One can survey the applications of one machine-learning paradigm in computer games from multiple genres. One can survey the applications of multiple machine-learning paradigms in computer games from multiple genres. Justesen

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and others have co-authored such a survey (Justesen et al. 2020). Machine-learning frameworks, representations, architectures, and algorithms covered in their survey include Deep Q-network (DQN), Distributional DQN, Deep recurrent Q-learning (DRQN), Hierarchical DQN (h-DQN), LSTM (long short-term memory) network, hierarchical deep reinforcement-learning network (H-DRLN), Neural Turing Machines (NTMs), recurrent memory Q-network (RMQN), feedback recurrent memory Q-network (FRMQN), teacher-student curriculum learning (TSCL) framework, Independent Q-learning (IQL), multiagent bidirectionally coordinated network (BiC-Net), convolutional neural-network-fitted Q-learning (CNNFQ), LSTM-DQN architecture, deep reinforcement relevance net (DRRN), deep distributed recurrent Q-network (DDRQN), Double DQN, dueling DQN, and Prioritized DQN. Q-learning is a reinforcement-learning algorithm.

One can survey genre-independent applications of one machine-learning paradigm in computer games. One can survey genre-independent applications of multiple machine-learning paradigms in computer games. A survey can also be driven by tasks related to computer games and machine learning. So one can survey uses of machine learning to solve tasks related to computer games. This chapter is a survey that covers some of the important applications of different machine-learning paradigms to computer games such that the methodology in these applications is either genre-independent or can be generalized to make it applicable to additional genres. This survey is organized by the abstract computer-game-related tasks addressed by one or more machine-learning paradigms.

Recognizing Genre Based on Audio

Amiriparian and others (2020) introduce game-audio-based genre recognition and present an approach to solve this problem. They extract the following three feature representations from game-audio files: knowledge-based acoustic features, DEEP SPECTRUM features, and quantized DEEP SPECTRUM features using Bag-of-Audio-Words. They considered recognition of the following six genres: Action or Shooter, Arcade or Platform, Fighting, Racing, Sports, and Simulation or World Building. They trained a linear SVM (support vector machine) classifier. They found that Racing games were the easiest to recognize due to automotive noises and Simulation and World Building games were the most difficult to recognize.

Game Balancing

A game is unbalanced when it is too easy or too hard for the human player. This imbalance can cause the player to lose interest in playing the game. According to Andrade and others (2005), dynamically balancing a game using reinforcement learning by giving a negative reward to the computer-controlled agent when the game is too easy or too hard is not a good solution to the game-balancing problem, as this solution can result in unbelievable behaviors like the computer-controlled agent not using defense at all after hitting the character controlled by the human player. Their challenge-sensitive action-selection mechanism requires the computer-controlled agent to periodically use the challenge function to evaluate if it is at the same level as the player. According to the challenge function proposed by them for a fighting game, whether the game is easy, moderately hard, or difficult, depends on the difference in the lives of the computer-controlled character and the human-controlled character. They used modified reinforcement learning. According to their approach, the computer-controlled agent progressively chooses sub-optimal actions if the game is too hard. Their modification to reinforcement learning resulted in the computer-controlled agent exhibiting win-loss balance.

Testing Hypotheses

Akbar and others (2021) used ensemble learning to test if inclusion of adult content allows a mod to

get more endorsements. The ensemble included recurrent neural networks (RNNs) and decision forest models. They found that adult content played an important role in determining the endorsement count of a mod.

Transferring Learning for Fulfilling New Tasks

Braylan and others (2016) propose GRUSM (General ReUse of Static Modules) for transfer learning. A GRUSM network is a 3-tuple G' = (M', S′, T') where M' is a traditional neural network (feedforward or recurrent) containing the new nodes and connections unique to the target task, with input and output nodes corresponding to inputs and outputs defined by the target domain; S′ is a (possibly empty) set of pointers to recruited source networks; and T' is a set of weighted transfer connections between nodes in M' and nodes in source networks (Braylan et al. 2016). Each source network can be a traditional neural network or a GRUSM network. Source networks are existing neural modules.

Improving Behavior Trees

A behavior tree represents behaviors at multiple levels of abstraction such that the behaviors at the lowest level are executable. Behavior trees can be used in computer games for controlling computer-controlled characters (non-playing characters). The root of a behavior tree for preys in (Dey and Child 2013) is the selector node. Its children are *Retreat*, *Idle*, and *Attack*. The children of *Retreat* are *Flee* and *SeekSafety*. The children of *Idle* are *Graze* and *Explore*. The children of *Graze* are *Forage* and *Eat*. The children of *Explore* are *Flock* and *Wander*. The children of *Attack* are *Charge* and *Assist*. *Assist* means attacking the nearest predator agent targeting a neighboring prey agent. The main goal in (Dey and Child 2013) is development of an approach for suggesting changes to a behavior tree, to assist game designers. Q-learning is used in (Dey and Child 2013). Their approach prioritizes the behaviors in a behavior tree based on their utilities.

Behavior Cloning

Since playing against superhuman opponents can be frustrating to human players, Diels and Kazmi (2021) propose cloning behavior of human players to create realistic opponents. They evaluate a behavioral clone of a game-playing agent by comparing action distributions and by comparing play-style data. They tried to clone a reinforcement-learning agent that was not allowed to improve after the training phase, a random agent sampling actions uniformly, and a human player. They show that cloning the behavior of a human player is more difficult than cloning the behavior of other agents since humans play least consistently.

Learning from Visual Game Display

NPCs (non-playing characters) are broadly defined as visible components of a game that are under the control of the computer, and that either work with or against the human player (Fink et al. 2007). Fink and others use machine learning to learn the behavior of NPCs from just the graphical output of the game generated during game play. They claim that this can be useful for knowing what the human player may learn during game play. The learnt behavior can be compared with the implemented behavior to know how well the human player can learn the implemented behavior. They claim that their method can be used to re-engineer the game if game code is not available. They use a similarity function and nearest-neighbor rule.

Personalizing Challenges

The framework (Georgiou and Demiris 2016) for altering the segments of a racing track according to model of the user uses linear regression for

finding weights of physiological and non-physiological metrics. Physiological metrics include metrics based on eye tracking and head pose. Non-physiological metrics include metrics obtained from player inputs and game outputs.

Selecting Animations Better

Gillies (2009) points out that the individuality of a real actor's performance should be reflected not only in the appearance and animation of the character, but also in the AI that controls the character's behavior and interactions, in games containing characters based on real actors. I-O HMM (input-output hidden Markov model) is used in this work to learn the transition probabilities for the finite-state machine and the function that selects edges of the motion graph based on the current state. A motion graph allows animations to be generated by sequencing preexisting animations. Each edge of this graph is associated with an animation clip. There is a probability for each edge of the motion graph. A node of the motion graph is a point at which an animation clip can be selected.

Making Agents Human-Like

To make computer-controlled characters believable by having them move like human-controlled characters, Gorman and Humphrys (2006) recorded locations of the character controlled by the human player and clustered these locations. Each of these clusters is a node in the directed graph which has an edge from node i' to node j' if the human-controlled character was observed to move from i' to j'. They used reinforcement learning. The rewards were designed to encourage the computer-controlled character to follow the routes of the human-controlled character.

Using Games to Improve Machine Learning

Greengard (2017) is a brief review of work relating autonomous driving, machine learning, computer games, and simulations. It is much easier to create diverse and unforeseen roads and surroundings fast at a much lower cost in virtual world, to get a large amount of data for machine learning for autonomous driving.

Recognizing Social Context

Li and others (2010) introduce a multiplayer, collaborative version of Tetris. Each of the two players can control one of the two falling pieces. Each player played on a separate computer separated by a shelf in their experiments. They recorded the players' eye movements. The four social contexts considered by them were NN (a novice playing with another novice), NE (a novice playing with an expert), EN (an expert playing with a novice), and EE (an expert playing with another expert). EN and NE are different categories since the type of the first player in these combinations is different, and this matters in interpretation of the statistical information found for the first player in a pair. They found that gaze on self was strongest for players in NN pairs. They found that gaze on self was weakest for expert players when playing with novice players. Action features they used were intended to capture playing style. Action features were found using type of moves (rotations, translations, drops, and downs) and distances associated with these moves on the grid. They used SVM (support vector machine) classifiers. They show that it is possible to recognize social context based on gaze and action features.

Relating Game-Related Preferences to Social-Network Data

Lim and Harrell (2013) used social-networking information to predict the likelihood of players customizing their profile in several ways associated with the monetary values of the players' avatar. They used clustering and SVMs. They show that a strong relationship exists between a player's real-world identity and virtual identity within games.

Automated Story Generation

Martin and others (2018) define *automated story generation* as the problem of automatically selecting a sequence of events, actions, or words, that can be told as a story. They formalize automated story generation as sampling from the probability distribution over successor events when a sequence of events is given. They use a recurrent encoder-decoder network to produce the probability distribution. They introduce *event2sentence*, which is a neural network for translating an event into natural language.

Generation of Game Stages

Nam and others (2022) train reinforcement-learning agents to generate diverse and enjoyable stages of a game. A stage is a series of events in a turn-based role-playing game. They represent each stage using a matrix containing real numbers. An empty stage is represented by a matrix filled with zeros. Actions fill an incomplete stage matrix sequentially by deciding one or more of its elements. The stage-evaluation function serves as the reward function.

Predicting Opponent's Strategy

StarCraft is a real-time strategy (RTS) game requiring tactics, strategies, and resource management. Opponent's territory is not fully visible in this war game due to fog. Park and Cho's approach (Park and Cho 2012) involves sending a scouting unit to the opponent's territory to find information about the opponent's structures and units, so that it can be used for machine learning. They used 13 machine-learning algorithms. These included algorithms using decision trees and neural networks. Opponent's strategy is predicted to be fast or slow. The opponent's strategy is fast if it attacks first, otherwise it is slow.

Camera Selection

Passos and others (2009) demonstrate an intelligent editor agent for deciding shot transition. There can be multiple cameras, e.g., chasing camera, front camera, and high-view camera. The camera used affects what the human player sees on the screen, and this affects gaming experience considerably. The approach in (Passos et al. 2009) uses a neural network for each camera and decides which camera to use in the current situation based on the classifications provided by the neural networks.

Detecting and Adapting to Novelty in Games

Peng and others (2021) point out that policies of reinforcement-learning agents are often fine-tuned to the mechanics of the environment, but assuming that the state space, action space, and transition dynamics of the world do not change over the life of the agent is not practical in many domains. They define *open-world novelty* as a change in the observation types, action types, environment dynamics, or any other change in the world mechanics that makes it different from the world originally used to train the agent. They propose a deep-reinforcement-learning technique for detecting and adapting to open-world novelty in games. Their system maintains two knowledge graphs. One of them represents the state of the world and the other represents the rules of the game. Their system detects novelty by detecting a change to static entities and relations of the state-knowledge graph or to the rule graph.

Automated Creation of Faces of Game Characters

Shi and others (2022) point out that customizing the face of a character is very time-consuming even for experienced players as there are too many parameters whose values need to be adjusted. Their method automatically creates face of a character based on a single photograph of face. Their method transforms the input image into a set of in-game facial parameters. They use deep convolutional neural networks (CNNs).

Detecting Player Burnout

Smerdov and others (2021) point out that physiological data may provide new insights into a player's behavior. They assert that though in-game data can be useful in player-skill assessment, match analysis, match-outcome prediction, and post-match analysis, models trained on in-game data can become obsolete because of new patches or changes in game mechanics. They collected sensor data from humans playing eSports. This data is about pulse, saccades (rapid eye movements between fixation points), muscle activity, galvanic skin response (GSR), mouse activity, keyboard activity, facial-skin temperature, electroencephalogram (EEG), environmental temperature, relative humidity, carbon-dioxide level, pulse-oximeter data, and movements of chair, hand, and head. They used this data and machine learning to predict outcomes of encounters extracted from in-game logs. They used logistic regression, KNN (k-nearest neighbors algorithm), GRU (gated recurrent unit) neural network, and transformer neural network. Their observations include the following: (i) The feature indicating good in-game activity the most is the intensity of gamma waves for the T7 electrode located near the left temple. (ii) Higher heart rate and eye activity increase the player's performance. (iii) The feature most important in predicting that the player is likely to lose the next fight is vertical movement of the chair. (iv) Higher environmental temperature, humidity, and carbon-dioxide level decrease the player's performance. (v) Higher facial-skin temperature, GSR, and pupil diameter lower the probability of winning the next fight, as these are related to a lower concentration, higher mental load, and stress.

Classification of Team Behaviors

A Hidden Markov Model (HMM) is trained for each team behavior (Thurau et al. 2006). They classified observation data into one of five behaviors. The names of these behaviors followed by their descriptions from (Thurau et al. 2006) are as follows: **dribbling** (one player possesses the ball and the other player follows), **given-and-go** (the ball is passed back and forth between two players), **ball retrieval** (one player runs toward the resting ball and passes it to the other player right away), **long pass** (the ball is passed over a longer distance and not returned), and **solo** (the player with the ball does not pass the ball but constantly moves in one direction, and the other player runs alongside).

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Macroscopic Simulation

► Crowd Evacuation Using Simulation Techniques

Madden NFL and Infinite Inspiration

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Synonyms

Sports video game

Definition

Sports video game	A genre of games that replicates how a sport is played in a video game format

History of Madden NFL

The lens of infinite inspiration proposes that instead of looking at a game for ideas, one should look at everything else. If one looks only at a game or games like the one they are creating, the game might seem like an imitation. Instead, look for inspiration in the world. In Jesse Schell's book "The Art of Game Design: A Book of Lenses," the Lens of Infinite Inspiration states that "to use this lens, stop looking at your game, and stop looking at games like it. Instead, (Schell, 2019) look everywhere else." The Lens of Infinite Inspiration asks the following questions:

1. What is an experience I have had in my life that I would want to share with others?
2. In what small way can I capture the essence of that experience and put it into my game?

Madden NFL 19 is a sports video game about the professional American football league. This game captures the experience of a game that some cannot play due to physical handicaps or a lack of means. The game inspires young children to go out and try football in real life. It was created because someone wanted to share an experience

they had with other people (Madden NFL 19, 2018).

The next part of the lens of infinite expression is conveying an experience into the game. In what ways can an experience in the game match the experience the players will feel? The four elements that need to be conveyed are mechanics, story, esthetic, and technology.

Mechanics are rules and controls that the game will have; its what makes a game feel real. *Madden NFL 19* uses many mechanics to enrich the gameplay. The game has a mechanic the allows players to perform skill moves. Skill moves are things like hurdling over a defender or attempting to knock the ball out of the offender's hands. These mechanics give the player a glimpse of what it is like to play in a professional football game. Using mechanics to imitate real life experiences makes a game interesting and unique.

The next element that is used to capture the experience is the story. This can enhance the experience by allowing the player to make choices throughout the game that will determine the ending. In *Madden NFL 19,* there is a story mode that has a young man fighting his way up the ladder to play in the professional league. The player gets a feel on the experience many young men have as they struggle to play professional football. The story is about the life of the game that is portrayed.

The esthetic is how a game looks and sounds. The art and soundtrack will immerse the player into the setting of the game to bring out the experience through their senses. *Madden NFL 19* makes the art as realistic as possible. The developers scanned the players to make the in-game models nearly identical to the real players. They made realistic stadiums with a soundtrack that enhances the experience. If the games' art and sound match the experience, the game will stand out.

The technology is anything that makes the game possible. Inspiration can allow for new technology for a game to be developed. In *Madden NFL 19,* the developers made use of microphones to allow the play to give voice commands to the game. An example of this is saying time-out so the game will call time-out for you. Technology can make a game very unique if one is willing to create new technology to allow for a better experience.

To make a game something special, it needs to have an inspiration, such as personal experience. Imitating other people's inspiration can lead to a game that lacks emotion. Use an experience and the four basic elements to create a game from a unique inspiration.

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Making Virtual Reality (VR) Accessible for People with Disabilities

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Synonyms

Accessibility; Augmented reality; Blindness; Cognitive disabilities; Learning disabilities; Mixed reality; Physical disabilities; Sensory disabilities; Virtual reality; Visual impairment

Definition

Virtual reality (VR) is a simulated digital environment that obstructs the real world, creating an immersive experience that can imitate real-world physical properties.

Accessibility in technology refers to the practice of making technology and digital environments usable by as many people as possible.

Physical disabilities are medical conditions that diminish an individual's capacity for physical movement.

Cognitive disabilities or disorders are medical conditions that affect an individual's brain function by limiting the brain's capacity to collect, process, understand, or store information.

Sensory disabilities are neurological disorders that affect the human brain's ability to process sensory information, that is, sight, hearing, touch, taste, and smell.

Introduction

Virtual reality (VR) requires the use of specialized hardware to allow the user to partake in an interactive virtual experience. Examples of this hardware include headsets and motion controllers to interact with the virtual environment. Handling a headset requires the usage of the user's body parts, like neck and shoulders, and upper body strength to support it while being susceptible to movement. These headsets rely on the user's eyes, often leaving little-to-no room for glasses. In addition, motion controllers require the use of the user's hands and arms to take part in most VR gaming experiences, immediately excluding disabled users who may not be able to use this hardware as intended, keeping people with disabilities from participating in most VR experiences. However, as VR technology becomes more popular and its development and techniques are further explored, some alternatives have been proposed to make sure people with disabilities can experience VR. Through the article, examples of accessible approaches for the development of VR gaming will be presented, focusing on people living with physical impairments, visual impairments, and cognitive disabilities.

Disabilities and Their Impact

According to the World Health Organization in World Health Organization (2021), over one billion people (15% of the world's population) are living with some form of disability. This number is growing because of demographic trends, the increasing rate of chronic health conditions, and other causes. Therefore, it is likely that everyone will experience a disability in some form or another at some point of their life. Disabilities can take various forms, physical, cognitive, sensory, or other. Each disability brings its challenges to the individual's life and unique accessibility needs for the user to engage with VR. Headsets are often bulky, causing accessibility issues for users with weak neck and shoulder strength. According to The 360 Guy (2022), VR headsets range in weight from 468 grams (1 lb, 0.5 oz) to 644 g (1 lb, 6.7 oz). Users who cannot support this weight while performing actions required by the VR application have few options.

Motion controllers often require the user to hold them at specific positions, point them in a direction, and make mid-air motions (Heilemann et al. 2021). Disabilities that prevent someone from raising their arms and moving their hands can prevent them from using motion controllers and many VR applications that depend on these controllers for input. An implicit assumption of these motion controllers is that the user has one or both hands available and has fine and gross motor control to perform precise and large movements (Mott et al. 2020). This may not always be the case, as many physical disabilities can severely limit an individual's ability to perform these required motions, thus preventing them from engaging with VR and presenting a significant barrier to entry.

Sensory disabilities can also impact the user's ability to partake in VR. Users with visual disabilities may find text instructions difficult to read, requiring the application to support descriptive audio or additional audio cues to guide them. However, including these additional accessibility features is a choice made by the developers of the application. Conversely, users with auditory disabilities can experience difficulty hearing important sounds or speech and may depend on the application's developers, including subtitles as an accessibility aid.

Each manufacturer of VR equipment has their standards, locking games to specific hardware that may not support the accessibility features a disabled user requires (W3C Working Group 2021). This presents an additional barrier to entry as not having the accessibility of VR hardware standardized across different manufacturers leaves the

inclusion of accessibility features to each manufacturer's discretion.

VR Gaming for People with Physical Impairment

Physical disabilities can prevent individuals from using VR for a variety of reasons. Depending on the disability, different actions required by the virtual environment can be difficult to impossible for a disabled person to perform. Because the VR headset tracks the position of the user's head in 3D space and various applications expect the user to stand, people who cannot stand negatively impact their experience.

WalkinVR is an assistive tool that enables a third party to alter the position of the VR user in 3D space, use action buttons on the controller, or grip game objects (WalkinVRDriver 2022a). For individuals that cannot perform actions such as standing, crouching, or lying prone, WalkinVR also provides assistive functionality that enables users to create additional controller bindings that mimic these actions. By adding this functionality, users with disabilities that prevent these actions can partake in environments that require them (WalkinVRDriver 2022b).

Another accessibility feature WalkinVR provides is adjusting the position of a motion controller in VR. Environments can have physical expectations of the user, such as raising the motion controller to a specific height (e.g., eye or shoulder level) or extending the motion controller a distance away from their body, which a disabled user may find difficult or impossible. The user can also change the scaling of real-world movements to virtual movements (i.e., an 8 cm movement on the real controller can translate to a 30 cm movement within the virtual environment). WalkinVR's functionality of adjusting the motion controller's position and increasing the scaling of real-world to virtual moments enables disabled users to overcome these barriers to entry (WalkinVRDriver 2022c).

And finally, another accessibility issue that WalkinVR addresses is the requirement of using motion controllers to engage with virtual environments. People with disabilities that cannot hold motion controllers can now engage with VR by using their hands as the controller to a limited degree. Integrating a Microsoft Kinect 2.0 or Kinect 360 allows a user's hands to act as a motion controller for environments requiring a player "touching" something within them. The VR environment now uses the position of the user's hands in place of the controller, thus enabling people with disabilities that prevent them from holding or grasping a motion controller to engage with VR (WalkinVRDriver 2022d).

The VR game Half-Life: Alyx, developed by Valve Corporation, is an example of a game with many accessibility options for physically disabled users. Players can choose their dominant hand to wield weapons and play in a seated mode where crouching and standing are done with the controller instead of physical movements (Rad 2020). The game provides additional accessibility features such as subtitles and closed captions, reducing the strength and flickering of lights in-game, and disabling "Barnacle Lift" (i.e., preventing an in-game enemy from lifting the player character off the ground. Instead, the player takes damage and remains in place).

Half-Life: Alyx also lets users change how they select their weapons from the in-game context menu. Instead of using their hand to point at and select a weapon, the user can do this using their head. Disabled users with difficulty with fine motor skills have other options that may be more accessible to them.

VR Gaming for People with Learning Disabilities

The approach of adopting video games as a way for people with cognitive disabilities to develop or improve learning skills has been around for a couple of years, and this approach has been applied to different types of disabilities such as Autism, Dyslexia, Dyscalculia, Dysgraphia, etc. In addition, some video games and mobile applications have been developed with the intention of identifying whether a user might have some type of learning disability rather than

immediately addressing a specific type. Results have shown improvements in the different areas where it has been applied. However, with the recent spread and popularity of VR, specifically in the gaming sector, the development of VR games directed to address cognitive disabilities constitutes the next step for further gaming developers. The possible advantages of a fully immersive gaming experience to enhance and facilitate learning in different areas should be explored to create a more inclusive gaming community and to take advantage of new technologies as a helping tool for people with cognitive disabilities.

A project was founded in 2018 by the US Department of Education, aiming to use VR to help students with learning disabilities in schools all over the country. The University of Kansas developed the "VOISS: Virtual Reality Opportunities to Implement Social Skills" project to address the challenges in the development of social skills for students with disabilities. VOISS uses a VR Head-mounted Display (HMD) set that allows subjects to enter a controlled virtual environment where they can walk around in different locations like hallways, locker rooms, classrooms, etc. Recreating interaction scenarios with computer-driven avatars allows the user to evaluate an interaction's positive or negative consequences. The fundamental goal is to use VR to explicitly teach students social skills and the proper way to apply them in natural environments (Gera 2018).

According to cognitive science, virtual experiences can enhance cognitive flexibility in non-digital environments. To become an adequate learning tool, digital environments must keep a sense of realism. This realism creates a relationship between the consequences of learned actions in a virtual environment and the real world.

Ahn's work intended to elaborate on the effects of combining VR and a computer video game for cognitive-based therapy with a group of 13 children between the ages of 7 and 13 years and the capacity to play a game for 20 min and follow verbal instructions (Ahn 2021). Subjects took part in four sports games using a Wii console and a motion-based VR game. To study the differences in visual-motor integration, the second editions of the Bruininks-Oseretsky Test of Motor Proficiency and Developmental Test of Visual Perception were implemented to analyze changes in function for visual-motor integration and to identify changes in visual perception.

Results showed the effectiveness of VR and computer game-based therapy to approach cognitive disabilities by appealing to visual perception and motor function in children with these types of disabilities, demonstrating a considerable improvement of scores for both examination methods after exposure to VR gaming therapy for specific elements such as visual motor integration and general visual perception.

Research conducted by Kim et al. (2019) focused on VR intervention's effectiveness as a therapy method for people with mild cognitive impairment or dementia, gathering results from 11 different studies highly focused on VR. Kim et al. compared the results from studies that used a full-immersive VR experience to studies using semi-immersive technology and found a small-to-medium effect ratio in patients exposed to VR intervention techniques, especially in factors such as physical fitness, cognition, and emotion. Aiming to set boundaries for a standardized guideline for VR intervention in patients, the research intended to summarize evidence to validate the use of VR in this healthcare area.

VR Gaming for People with Visual Impairment

Most video games rely on visual elements to guide the user, leading to unintended exclusion for people with some degree of visual impairment. Even though some features like screen reading and options for size adjustment exist in some games, these approaches do not ensure people with sight loss can experience gaming to its full extent. The lack of inclusive options increases with emerging technology, which is the case with VR gaming. However, it is important to point out that blind individuals develop other senses to a larger extent, such as hearing,

smelling, and touching. That is why VR gaming is an excellent area of opportunity to enhance the user's experience while gaming without the use of visual stimuli. Making the most of other elements like audio and haptics can ensure an entertaining gaming experience. Recent developments were made to create VR gaming options for the blind community. However, mainstream VR games are not designed to adapt to the needs of people with sight loss.

One game prototype is The Enclosing Dark, created by Gluck and Brinkley in 2020. It is a VR adventure game that was designed as a game option for the visually impaired. Pre-game training teaches the user how to understand the audio and haptics and interact with the virtual environment. Audio and haptics are combined to provide feedback about the invisible landscape where the game takes place. Audio is mainly used to communicate with the user and describe the actions of the player's avatar, from footsteps to rotation. Spatial audio is applied to create a simulation of the natural environment, allowing the user to build a mental map through the auditory output. Haptics is a medium to deliver supplemental information about the virtual environment through three different vibration patterns. The first one is used to aid in the location of obstacles, the second one provides feedback when hitting an enemy, and the third one gives additional information about the surroundings (Gluck and Brinkley 2020).

In 2021, a VR archery game that had no visual elements was created. The main purpose behind it was to assess if early blind adults would show less developed head-trunk coordination, as sensory disabilities have a direct impact on motor development. It was tested by letting early blind and sighted individuals play it and compare the results. The hardware used was the game engine Unity 3D, BOSE over-ear headphones, and a LG Google Nexus 4 smartphone. The user had to lead an arrow to hit the center of a target by a combination of head and trunk rotations around the vertical axis (Esposito et al. 2021).

Also, in 2021, Racing in the Dark was developed. It is a fast-paced VR racing game accessible to the blind community, as it takes advantage of the elements built into the Oculus Quest VR headset. With its haptics, tracking, auditory, and voice systems, a nonvisual experience is provided to the user. The game consists of a car race against four artificial intelligence opponents on a three-and-a-half-mile virtual track. The first one to complete three laps over the track wins. Haptic feedback is the primary source for providing the player with information about the racetrack without any visual input. Also, with the controllers' hand gestures tracking, the player can provide input to the game. In addition, vocal input is used to communicate with the artificial intelligence pit crew. Finally, audio output is used to create a more immersive experience, as it was not suitable for information transmission because it was too slow to create a fast-paced experience (Gluck et al. 2021).

Conclusion and Discussion

It is important to consider the area of opportunity within the design of inclusive VR video games. Nowadays, mainstream VR games are usually not accessible to people with disabilities. However, headsets expand possibilities and allow those types of games to have a lot of potential for making the most of their features and creating an accessible experience for everyone. Elements like haptics, controllers, visual output, and audio output should be considered when designing a VR game. There are a few developments and adaptations of video games to make them accessible. However, the work done is not enough to ensure that VR gaming is accessible for people with disabilities. In addition, the advantages obtained from the use of VR gaming in different therapy techniques have been shown in recent research, highlighting the importance of pushing VR gaming to become more accessible for people with disabilities. Aiming for a more inclusive society and gaming community, people with disabilities can benefit from entertainment improving the state of their condition through VR therapy in some cases.

Cross-References

- ▶ Accessibility of Virtual Reality for Persons with Disabilities
- ▶ Immersive Technologies for Accessible User Experiences
- ▶ Mindfulness, Virtual Reality, and Video Games

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Management

- ▶ Game Development Leadership Tips

Many-Light Rendering

- ▶ High-Performance Many-Light Rendering

Mario Kart, an Analysis of Its Absence from Esports

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Synonyms

Racing games

Definition

Mario Kart is a Multiplayer Racing Game created by Nintendo. It allows up to eight players to race to the finish line by using various items to attempt to take the lead.

Introduction

As of December 2021, *Mario Kart 8* is Nintendo's highest selling Switch game, with over 43 million copies sold (Nintendo.co.jp). Despite the popularity and the competitive gameplay, Mario Kart has limited popularity in the professional esports scene. This entry discusses the positive and negative factors effecting Mario Kart in order to determine why it is missing from the professional esports scene (Esports Talks, 2018).

Four Positive Factors

William Collis, author of "Book of Esports: The Definitive Guide to Competitive Video Games," states four main factors that make a game an esports: the player's skills, the community surrounding the game, how accessible the game is to players, and how rewarding the game is to play (Collis, 2020 p.5). Another source from the esports-news.co.uk article titled "What Factors Help Create a Successful Esports Games" states that "Providing a game that is easy to learn yet hard to master, delivering quality audience experiences with spectator modes, title must have widespread appeal, and having simple goals set for players to achieve" (esports-news.co.uk) (Esports News UK, 2021).

In short, the most important factors for an esports game are:

1. Simple to learn but requires skills to master
2. Has a large community
3. Has a simple goal to achieve
4. Must be rewarding to become skilled

How does this relate to *Mario Kart 8?* As stated in the introduction, it is currently Nintendo's highest selling switch game. It would be reasonable to say that it has a large community backing (factor #2). The game is also quite easy to learn for new players but requires a large amount of skills to use items and drift abilities at the right time (factor #1). The goal of the game is to complete four races and earn points to be crowned the winner (factor #3). In the offline mode, when a player wins first place in a grand prix, they are rewarded with a trophy. If they get first place in all four races, they get a gold trophy for mastering the tournament. In online tournaments, the players are randomly assigned to a track. The points you earn either increase or decrease your score on the world leaderboards (factor #4). From this, we can deduce that the game is in line with all four goals.

Four Negative Factors

However, there are four factors that negatively hurt Mario Kart in the esports world. Chris Blain, a writer for Esportstalk.com, listed several reasons the game is missing from professional esports. His first point was the lack of tournaments. Mario Kart tournaments do not have official leagues, unlike many other popular games. The tournaments are mostly fan run, so the prize pools are too low for players to spend the time getting skilled at the game. His second point was the RNG factor. He stated the game has too much randomness and luck, but the game is quite boring without having at least some items available. His third point was that many of the courses are designed to allow players to cheat and take shortcuts, which can present an unfair advantage. His final point was the lack of team elements in the game – a feature that is common in almost all popular esports games (Blain). It should be noted that his fourth point is no longer valid because Nintendo has added team races in a game update.

Blain made some good points in his article. The game relies heavily on RNG. Many of the races could end because another player got lucky. However, luck is a factor that is common in most games. For example, a player could draw a good card right when they need it in Hearthstone. The cheating on tracks is a big factor, but this could be alleviated by either banning the cheatable tracks in official tournaments or adding rules to disqualify players who cheat. From his points, the only negative factor that cannot be easily removed is the lack of official tournaments.

Issues with Tournaments

The biggest negative factor for Mario Kart is the limited number of tournaments. In fact, Nintendo only recently started hosting official Mario Kart tournaments in 2021. They signed an agreement with PlayVS to create an official high school league, but not much has been done otherwise (ign.com). The closest thing that most players get to official tournament is the online matches that Nintendo occasionally host. These tournaments require you to be on the top of the world leaderboard at the end of the 3-day tournament in order to be crowned the winner. The winner of the tournament wins 2500 Eshop credits, which translate to roughly $25, which does not even cover half the cost of *Mario Kart 8*.

The unofficial leagues do not reward much either. According to esportsearnings.com, the highest earning player of 2022 earned $450 for the whole year. This is nothing when compared to Dota 2. The top earner, Mira, won $3,696,653. The 500th place winner made $2800, which is six times what Mario Kart paid out (esportsearnings.com).

Conclusion and Discussion

Mario Kart 8 has the potential to be a professional esports game. It has all the common traits needed to gain popularity. There are certainly some factors that need balancing, such as RNG and issues with track designs. Since Nintendo still actively adds new content to Mario Kart in 2022, there is still a potential. The biggest factor hurting the game's popularity in esports is Nintendo itself. While Epic, Tencent, and other companies have been actively involved in the esports scene since the release of their games, Nintendo has only recently started to allow officially licensed leagues in 2021. They have focused primarily on building tournaments for their other games, such as *Super Smash Bros Ultimate* and *Splatoon 2*, while ignoring their cash cow Mario Kart. The lack of official tournaments means that the winning prizes are too small to be enticing. If professional leagues are to take off, Nintendo must step up, offer bigger prizes, and most of all, listen to their fan base.

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Marketing

▶ Virtual Reality Retailing

Massively Multi-player Online Games, MMOG

▶ Peer-to-Peer Gaming

Massively Multiplayer Online Role-Playing Game (MMORPG)

▶ Virtual World, a Definition Incorporating Distributed Computing and Instances

MCG

▶ Mobile Cloud Gaming

MCTS

▶ Monte-Carlo Tree Search

Mean Average Precision (MAP)

▶ American Sign Language Detection

Measurement Instrument

▶ MEEGA+, Systematic Model to Evaluate Educational Games

Mechanics

▶ Design of Alienation in Video Games

Mediated Reality

▶ Augmented Reality for Maintenance
▶ Interaction with Mobile Augmented Reality Environments

Medical Education

▶ Virtual Reality Proton Beam Therapy Unit: Case Study on the Development

Medical Robot

▶ Healthcare Robots with Islamic Practices

MEEGA+

▶ MEEGA+, Systematic Model to Evaluate Educational Games

MEEGA+, Systematic Model to Evaluate Educational Games

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Synonyms

Educational game; Evaluation model; Measurement instrument; MEEGA+; Serious games

Definitions

MEEGA+ is a systematic model to analyze educational games (digital and nondigital ones) in order to evaluate their perceived quality from the students' perspective in the context of computing education (Petri et al. 2016, 2017a).

Introduction

In the last years, games have also been used for different purposes than entertainment, being more and more used in educational contexts (Abt 2002; Connolly et al. 2012; Battistella and Gresse von Wangenheim 2016). Educational games are supposed to be an effective and efficient instructional strategy for teaching and learning in diverse knowledge areas such as mathematics, health, computing, and nutrition (Connolly et al. 2012; Calderón and Ruiz 2015). Especially in

computing education, there is a vast variety of educational games to teach computing competencies mainly in higher education (Battistella and Gresse von Wangenheim 2016). The majority are digital games, principally PC (Personal Computer) games, with a considerable trend also to nondigital ones (paper and pencil, board games, etc.). Predominant are simulation games, which allow students to practice competencies through the simulation of real-life situations in a realistic environment while keeping them engaged in the game (Battistella and Gresse von Wangenheim 2016). On the other hand, there also are several games designed to teach computing aiming at learning objectives at lower cognitive levels. Typically, these games are used to review and reinforce knowledge taught beforehand using different instructional strategies (Battistella and Gresse von Wangenheim 2016). These games are expected to be an effective and efficient strategy for computing education (Backlund and Hendrix 2013). However, these claims seem not rigorously established as most evaluations of educational games are performed in an ad hoc manner in terms of research design, measurement, data collection, and analysis (Calderón and Ruiz 2015; Petri and Gresse von Wangenheim 2017) due to the absence of models that provide a more systematic support for the evaluation of educational games (Petri and Gresse von Wangenheim 2016). Existing models for the evaluation of games typically focus only on specific quality factors, such as usability (Omar and Jaafar 2008), engagement (Brockmayer et al. 2009; Norman 2013), or player experience (Denisova et al. 2016; Abeele et al. 2016), not providing a more comprehensive analysis of the games' quality, and, in particular, not evaluating their impact on learning, being one of the main objectives of educational games. In this context, the MEEGA model (Savi et al. 2011) being developed since 2011 seems to be the most widely used evaluation model in practice (Calderón and Ruiz 2015; Petri and Gresse von Wangenheim 2017). MEEGA is a model developed for the evaluation of the quality of educational games in terms of motivation, user experience, and learning (Savi et al. 2011). Yet, although demonstrating an acceptable validity and reliability, a more comprehensive analysis of the initial version of the MEEGA model has identified improvement opportunities mainly related to an overlap of theoretical concepts of the factors motivation and user experience (Petri et al. 2017b). Consequently, the model has been revised resulting in a new version, the MEEGA+ model, which evaluates educational games in terms of usability and player experience. Thus, this article presents the design and evaluation of the MEEGA+ model, as an evolution of the MEEGA model proposed by Savi et al. (2011).

The MEEGA+ Evaluation Model

The objective of the MEEGA+ model is to analyze educational (digital and nondigital) games in order to evaluate their perceived quality from the students' perspective in the context of computing education (Petri et al. 2016, 2017a).

Evaluation Dimensions

With respect to this objective, the perceived quality is evaluated in terms of quality factors and dimensions. Based on a literature review (Petri and Gresse von Wangenheim 2017) and a systematic analysis of the initial version of the MEEGA model (Petri et al. 2017b), a set of dimensions was defined to be measured by the MEEGA+ model: focused attention, fun, challenge, social interaction, confidence, relevance, satisfaction, usability, and perceived learning (Table 1). The dimension usability is further fragmented into five subdimensions: learnability, operability, aesthetics, accessibility, and user error protection. A detailed description of the definition of dimensions can be found in Petri et al. (2016, 2017a).

Measurement Instrument Items

Data collection is operationalized through a measurement instrument (questionnaire). The measurement instrument items were derived based on the defined dimensions, improving the initial

MEEGA+, Systematic Model to Evaluate Educational Games, Table 1 MEEGA+ measurement instrument items

Dimension/Subdimension		Item No.	Description
Usability	Aesthetics	1	The game design is attractive (interface, graphics, cards, boards, etc.)
		2	The text font and colors are well blended and consistent
	Learnability	3	I needed to learn a few things before I could play the game
		4	Learning to play this game was easy for me
		5	I think that most people would learn to play this game very quickly
	Operability	6	I think that the game is easy to play
		7	The game rules are clear and easy to understand
	Accessibility	8	The fonts (size and style) used in the game are easy to read
		9	The colors used in the game are meaningful
		10	The game allows customizing the appearance (font and/or color) according to my preferences
	User error protection	11	The game prevents me from making mistakes
		12	When I make a mistake, it is easy to recover from it quickly
Confidence		13	When I first looked at the game, I had the impression that it would be easy for me
		14	The contents and structure helped me to become confident that I would learn with this game
Challenge		15	This game is appropriately challenging for me
		16	The game provides new challenges (offers new obstacles, situations, or variations) at an appropriate pace
		17	The game does not become monotonous as it progresses (repetitive or boring tasks)
Satisfaction		18	Completing the game tasks gave me a satisfying feeling of accomplishment
		19	It is due to my personal effort that I managed to advance in the game
		20	I feel satisfied with the things that I learned from the game
		21	I would recommend this game to my colleagues
Social interaction		22	I was able to interact with other players during the game
		23	The game promotes cooperation and/or competition among the players
		24	I felt good interacting with other players during the game
Fun		25	I had fun with the game
		26	Something happened during the game (game elements, competition, etc.) which made me smile
Focused attention		27	There was something interesting at the beginning of the game that captured my attention
		28	I was so involved in my gaming task that I lost track of time
		29	I forgot about my immediate surroundings while playing this game
Relevance		30	The game contents are relevant to my interests
		31	It is clear to me how the contents of the game are related to the course
		32	This game is an adequate teaching method for this course
		33	I prefer learning with this game to learning through other ways (e.g., other teaching methods)
Perceived learning		34	The game contributed to my learning in this course
		35	The game allowed for efficient learning compared with other activities in the course

version of the MEEGA questionnaire, and customizing and unifying existing standardized questionnaires found in literature (Savi et al. 2011; Keller 1987; Tullis and Albert 2008; Sindre and Moody 2003; Sweetser and Wyeth 2005; Poels et al. 2007; Gámez 2009; Takatalo et al. 2010;

O'Brien and Toms 2010; Wiebe et al. 2014; Fu et al. 2009; Mohamed and Jaafar 2010; Zaibon and Shiratuddin 2010; Zaibon 2015; Brooke 1996; Davis 1989). Table 1 shows the defined items for the MEEGA+ measurement instrument for each dimension/subdimension.

Response Format

The response format of the items of the MEEGA+ measurement instrument is a 5-point Likert scale with response alternatives ranging from strongly disagree to strongly agree (DeVellis 2016). The use of the Likert scale in its original 5-point format allows to express the opinion of the individual (student) under the object of study (educational game) with greater precision, besides allowing the individual being more comfortable to express their opinion, using a neutral point and, thus, increasing the quality of the answers (Dawes 2008).

Research Design

In order to conduct the evaluation in a quickly and nonintrusive way not interrupting the normal flow of the class, a case study design was chosen for the evaluation that allows an in-depth research of an individual, group, or event (Wohlin et al. 2012; Yin 2017). The general study design is a one-shot post-test only design, in which the case study begins with the application of the treatment (educational game) and afterwards the MEEGA+ questionnaire is answered by the students to collect the respective data. Adopting this research design, the evaluation objective is assessed based on the students' perceptions (perceived quality).

Data Analysis

Data collected in the case study are analyzed in terms of frequency distribution (through bar graphs) and central tendency (median) for each quality factor (usability and player experience) and their dimensions (Fig. 1). The MEEGA+ model provides a spreadsheet for the analysis of the data collected, assisting in the organization of the information and automatic generation of graphs visualizing the results of an evaluation.

The complete material of the MEEGA+ model is available in English, Brazilian Portuguese, and Spanish at: http://www.gqs.ufsc.br/meega-a-model-for-evaluating-educational-games/ under the Creative Commons License.

Evaluation of the MEEGA+ Model

In order to evaluate the reliability and construct validity of the MEEGA+ measurement instrument, 40 case studies were conducted, evaluating 18 different games applying the MEEGA+ model with a population of 718 students (Petri et al. 2018).

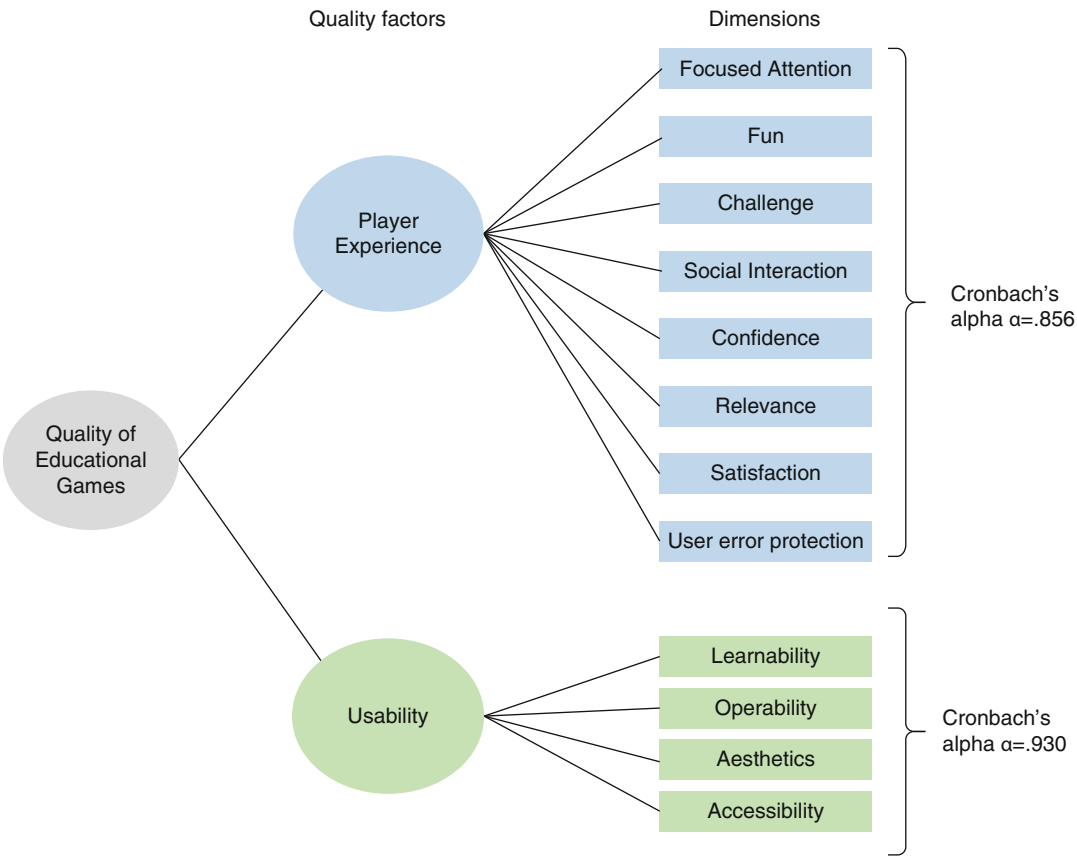
Reliability refers to the degree of consistency of the instrument items, typically, measured through the Cronbach's alpha coefficient (Trochim and Donnelly 2008). Analyzing the data collected, the value of the Cronbach's alpha for all items of the MEEGA+ measurement instrument is considered excellent ($\alpha = 0.928$). This result demonstrates that the answers to the items are consistent and precise, indicating the reliability of the MEEGA+ measurement instrument.

Construct validity refers to the ability to actually measure what it purports to measure, involving convergent and discriminant validity, which is obtained through the degree of correlation between the instrument items (Trochim and Donnelly 2008). In order to identify the number of factors that represents the responses of the items of the MEEGA+ measurement instrument, a factor analysis was performed. The results indicate that the structure of the MEEGA+ is based on an evaluation model with two quality factors and their dimensions, as presented in Fig. 2.

Analyzing the correlation between the items of the two quality factors (usability and player experience), the results show that there is a large correlation between most of the items within each quality factor. This indicates that a convergent validity can be established for the two quality factors (usability and player experience). In the same way, items of different quality factors present a small correlation, and, thus, provide evidence of discriminant validity. This indicates that the measurement instrument of the MEEGA+

Player Experience
Median
Challenge
This game is appropriately challenging for me. 0% 24% 24% 29% 24% 1
The game provides new challenges (offers new obstacles, situations or variations) at an 0% 29% 12% 35% 24% 1
The game does not become monotonous as it progresses (repetitive or boring tasks). 6% 18% 18% 41% 18% 1
Satisfaction
Completing the game tasks gave me a satisfying feeling of accomplishment. 0% 12% 24% 53% 12% 1
It is due to my personal effort that I managed to advance in the game. 0% 6% 29% 24% 41% 1
I feel satisfied with the things that I learned from the game. 0% 6% 18% 53% 24% 1
I would recommend this game to my colleagues. 0% 18% 0% 47% 35% 1
Social Interaction
I was able to interact with other players during the game. 0% 18% 29% 29% 24% 1
The game promotes cooperation and/or competition among the players. 0% 12% 12% 35% 41% 1
I felt good interacting with other players during the game. 0% 6% 35% 35% 24% 1
Fun
I had fun with the game. 0% 6% 24% 41% 29% 1
Something happened during the game (game elements, competition, etc.) which made me... 6% 18% 18% 35% 24% 1
Focused Attention
There was something interesting at the beginning of the game that captured my attention. 0% 18% 47% 24% 12% 0
I was so involved in my gaming task that I lost track of time. 18% 24% 35% 24% 0% 0
I forgot about my immediate surroundings while playing this game. 18% 41% 29% 6% 6% -1
Relevance
The game contents are relevant to my interests. 6% 29% 41% 24% 1
It is clear to me how the contents of the game are related to the course. 6% 53% 41% 1
This game is an adequate teaching method for this course. 6% 47% 47% 1
I prefer learning with this game to learning through other ways (e.g. other teaching methods). 0% 12% 24% 35% 29% 1
Strongly Disagree -2
Disagree -1
Indifferent 0
Agree 1
Strongly Agree 2

MEEGA+, Systematic Model to Evaluate Educational Games, Fig. 1 Example of data analysis graph provided by the MEEGA+ model



MEEGA+, Systematic Model to Evaluate Educational Games, Fig. 2 Decomposition of the quality of educational games in the MEEGA+ model

model is valid for evaluating the quality of educational games.

Conclusions

The MEEGA+ model, an evolution of the MEEGA model, aims at evaluating the perceived quality of educational games focusing on usability and player experience from the students' perspective in the context of computing education. Results of a statistical evaluation of the MEEGA+ measurement instrument demonstrate satisfactory reliability and construct validity. Thus, the MEEGA+ model can provide a reliable and valid measurement instrument for game creators, instructors, and researchers in order to evaluate the quality of educational games as a basis for their improvement and effective and efficient adoption in practice. And, although it has been originally developed for the evaluation of games for computing education, the MEEGA+ model can be used and adapted for the evaluation of games to teach other knowledge areas.

Cross-References

- ▶ Augmented Learning Experience for School Education
- ▶ Game Player Modeling
- ▶ Games and the Magic Circle

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Melee

▶ Super Smash Bros.: A Brief History

Memory

▶ Preserving the Collective Memory and Re-creating Identity Through Animation

Mental Disorder

▶ Virtual Reality Therapy

Mental Health of Indigenous Peoples

▶ Indigenous Knowledge for Mental Health, Data Visualization

Mental Immersion

▶ Virtual Reality: A Model for Understanding Immersive Computing

Mental Rotation

▶ Training Spatial Skills with Virtual Reality and Augmented Reality

Mesh Parameterization

▶ UV Map Generation on Triangular Mesh

Meta Artificial Intelligence and Artificial Intelligence Director

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Synonyms

Dynamic difficulty adjustment; Dynamic game balancing; Pacing

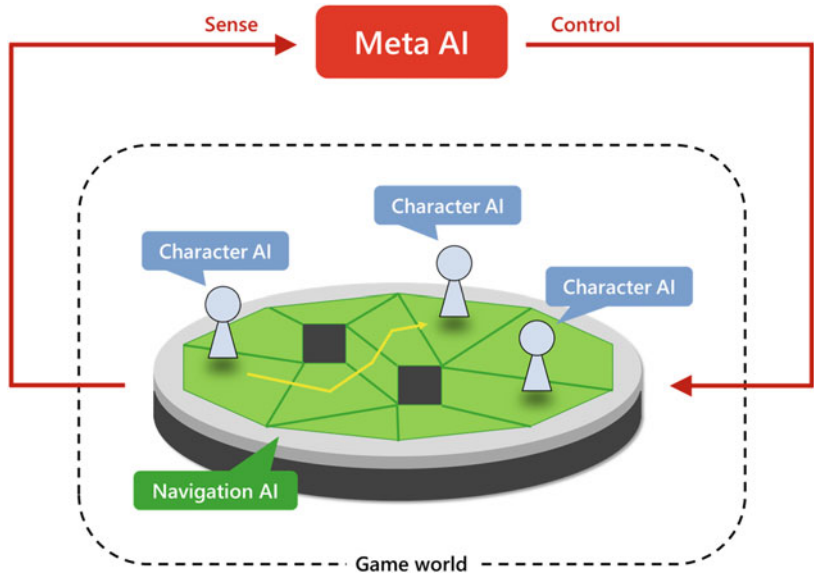
Definition

Meta Artificial Intelligence (Meta AI, as known as AI Director) is the set of processes used to control a whole game from a meta perspective.

Introduction

The main AI used in games can be classified into three types (Miyake 2017): character AI (see the ▶ "Character Artificial Intelligence" chapter) for representing characters, navigation AI (see the ▶ "Navigation Artificial Intelligence" chapter) for making environment information easy to handle, and Meta AI, which is described in this entry.

Meta AI is AI for controlling the whole game from the meta perspective (Fig. 1). For example, difficulty is generally adjusted in advance based



Meta Artificial Intelligence and Artificial Intelligence Director, Fig. 1 The basic idea of Meta AI. Character AI and Navigation AI work inside the game world. On the other hand, Meta AI controls the whole game from the meta perspective

on several standards such as "easy," "normal," and "hard." However, by introducing Meta AI, it is possible to dynamically change the difficulty and game balance according to the player's estimated emotions calculated by the gameplay data, making it possible to realize the optimum difficulty setting for individual players and game situations (see the "Combat Meta AI" section). In addition, it is difficult to optimally configure all events and objects beforehand in the wide game environment referred to as an open world. Using Meta AI makes it possible to dynamically control the events, characters, and other game objects encountered by players (see the "Non-combat Meta AI" section). Furthermore, Meta AI can make fun games actively through not only controlling the existing game but also generating contents such as music, terrain, or stories (see the "Conclusion and Discussion" section).

Meta AI Versus AI Director

AI Director is a similar term to Meta AI.

AI Director is a technology introduced for realizing adaptive dramatic pacing in order to increase the ability to replay (Booth 2009a, b). In Left 4 Dead (Booth 2008), this was accomplished through AI, which controls the intensity of the player by controlling the spawning pace of enemy characters.

Meanwhile, Meta AI is a technique advocated by Will Wright (2005) and utilized in his games such as The Sims (Wright 2000). According to Wright, Meta AI creates an experience by information flow, pacing, and a simple player model. This includes a peer AI, which controls agents, and a sub-AI, which governs simulations. Therefore, Meta AI is not limited to battles and can be understood to be an AI, which broadly controls the whole game.

Accordingly, in this entry AI Director is defined that optimizes certain parts of a game as a type of Meta AI and interpret the technology referred to as AI Director also as Meta AI.

Combat Meta AI

In this section, the authors describe Meta AI in a combat scene. Combat Meta AI can be broadly classified as (1) an approach that dynamically adjusts the difficulty of the game according to the changing battle situation and the state of the player throughout the battle and (2) an approach that dynamically adjusts the behavior, placement, and other game parameters of a nonplayer character (NPC) depending on the positional relationship of the characters and the battle situation. In this section, this is referred to as

pacing Meta AI, and tactical Meta AI, respectively.

Application of many of the methods introduced in this section is envisaged in situations where players and NPCs battle in the game, such as first-person shooter (FPS) fighting games or role-playing games (RPG). However, they are widely applicable to games that are designed to make players challenge the game system or NPC in some way, such as puzzle games, card games, board games, and other game parameters.

Pacing Meta AI

When and in what number should enemies make an appearance in a game where the enemies appear and are defeated one after another, such as in Space Invaders (Nishikado 1978)? For example:

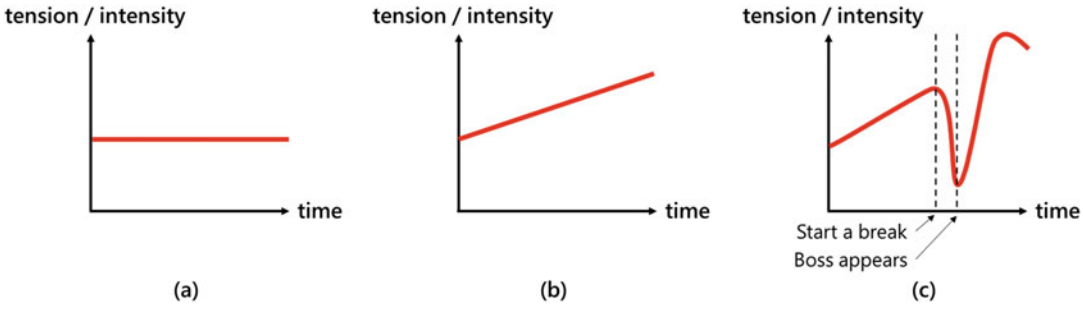
(a) Ten enemies appear per minute and continue to do so thereafter.
(b) Ten enemies appear in the first minute, 20 enemies appear in the next 1 min, and the number of enemies that appear continues to increase at the same pace.
(c) Ten enemies appear in the first minute, 20 enemies appear in the next 1 min, and after a 5-s break, the boss appears.

Of these cases, the third is an adequate pace for the flow of the game and would probably be found interesting. Figure 2 shows the player's expected chart of tension or intensity (called "interest curve") for each cases. Case (c) makes change that is more adequate in speed of the tension than others by using two events. Such game design techniques are widely known as pacing (Schell 2014; Rogers 2014).

Dynamic Difficulty Adjustment

In many games, the pace and difficulty of the game is predetermined by the game designer and does not change dynamically during play. The game designer carefully adjusts the parameters such that most players (or a representative player) experiences enjoyment. As a result, ten enemies appear in the first minute, and there is a 5-s break before a boss. However, as the skills of players and the game situations are diverse, it is not easy for every player to enjoy exactly the same content. Depending on the person, the game may be too easy or boring or it may be too difficult and make the player abandon the game. The basic idea of pacing Meta AI is to dynamically control the contents of the game according to the skill of the player and the game situation, such that various players experience a more interesting game. Within pacing Meta AI, the particular function that dynamically adjusts the difficulty level is called dynamic difficulty adjustment (DDA).

Various approaches are proposed for the method of creating a pacing Meta AI. The most classical method is to make difficulty adjustment rules in a form integrated with the game system. For example, Xevious (Endo et al. 1983) implements a simple Meta AI (Miller 2004; Cerny et al. 2005; Miyake 2017). The player's hidden "difficulty" evaluation score defines the enemy



Meta Artificial Intelligence and Artificial Intelligence Director, Fig. 2 Examples of the interest curve. (**a**) Enemies appear in a constant pace. (**b**) Number of enemies increases in a constant pace. (**c**) Using the pacing technique with the "Start a break" and "Boss appears" events

appearance pattern like "if the difficulty is 10 then three Type-A enemies appear" and "if the difficulty is 20 then four Type-A and five Type-B enemies appear." As long as the player proceeds in the game, increasingly stronger enemies appear, but when the player is defeated, the enemies return to weakness. This dynamically realizes a degree of difficulty that is just right for the player.

Emotion-Based Methods

In recent years, methods of separating the Meta AI from the game system and indirectly controlling it by digitizing the player and the game situation have been developed. In Left 4 Dead, Meta AI carries out pacing based on "emotional intensity" in order to realize repeated game playability and maintain interest (Booth 2009a, b). For example, if a player is damaged by an enemy, the evaluation value of emotional intensity increases in proportion to the amount of damage. The game flow is divided into four phases (build up, sustain peak, peak fade, and relax) in order to pace the emotional intensity throughout the game and the phases shift according to a player's behavior and emotional intensity. A similar Meta AI has been introduced in Warframe (Sinclair and McGregor 2013), where the speed of increasing intensity changes according to the growth of the player character (Brewer et al. 2013; Brewer 2014). Satoi and Mizuno proposed a Meta AI using a two-dimensional emotion model composed of "hope of winning" and "fear of losing" to measure and influence the player's various emotions (Satoi and Mizuno 2019). For example, in an action game, if the battle becomes deadlocked, Meta AI estimates the player's current emotion as bored and then tries to change it toward the opposite side of the emotion map by adjusting the enemies' behavior.

Balancing the Skills and Challenges

In the cases mentioned so far, the authors have focused on the pattern of change in difficulty and intensity according to the game progression, but it is also important to balance the skills of players and challenges. If players are to enjoy the game over a long period, situations should be avoided where beginners continue to fight strong enemies or advanced players are matched with weak enemies. Such a concept is modeled as flow theory and the state where the skill and the challenge are balanced is called a flow state (Csikszentmihalyi 1990). Flow theory has influenced game design theory and the DDA method (Salen and Zimmerman 2003; Hunicke and Chapman 2004; Chen 2007). Additionally, a framework for designing games to facilitate the achievement of a flow state has been proposed (Cruz and Uresti 2017).

The balance between the skill of the player and the challenge is considered to be particularly important in games where pacing cannot be based on the number of enemies spawned and the outcome of the game greatly depends on player skill, such as in fighting games. Therefore, several techniques for dynamically adjusting the behavior patterns of enemy characters in fighting games have been proposed in order to match enemy characters with players such that beginners and intermediate players can improve their skill while enjoying gameplay more. Demediuk et al. proposed an enemy AI that realizes DDA by trying to bring the difference in health points (HP) between the player and the enemy close to zero by changing the action selection policy and the Monte Carlo Tree Search (MCTS) evaluation function (Demediuk et al. 2017). In addition, Ishihara et al. introduced a term for reliability of behavior into the MCTS evaluation function and adjusted parameters according to the game situation, thereby realizing an enemy AI that can play with skills similar to that of the player and which seems natural (Ishihara et al. 2018).

Focusing on the Overall Engagement

Xue et al. proposed a method for increasing the overall engagement of a level-progression game such as a puzzle game. This method increases the cumulative number of levels played until the player leaves the game and the total duration of gameplay time. This was implemented it in a match three game released by Electronic Arts (Xue et al. 2017). The game progress is modeled as a stochastic graph composed of level up

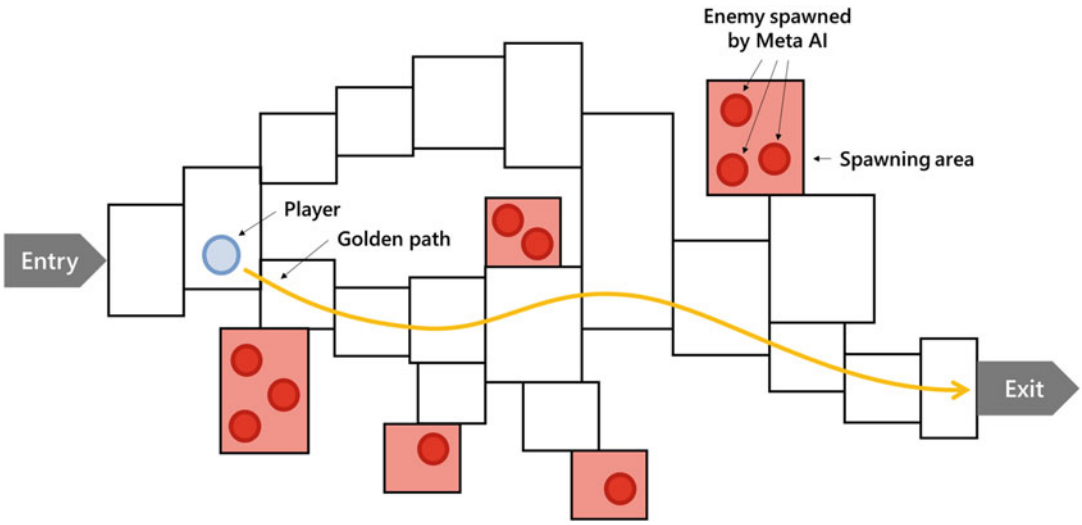
transition, retry transition, and churn transition. The optimum degree of difficulty in each state is calculated by dynamic programming.

Tactical Meta AI

In the previous section, the authors discussed a method of deciding when and by how much to adjust the contents of a game. In action games, real time strategy (RTS) games, and FPS, in which a battle develops in a vast virtual space, it is necessary to take into account "where" the game contents are to be adjusted, that is, the spatial element. For example, when you want to make an enemy NPC appear (spawn) to increase the intensity for a player, it makes no sense if it spawns at a distant location the player passed some time ago. Conversely, if the NPC spawns suddenly in front of the player, it probably causes a sense of discomfort or unnatural. Therefore, in game design it is necessary to calculate a "suitable location" at which to spawn the enemy NPC. There are a great number of methods for constructing tactics and strategies in game AI (Robertson and Watson 2014; Rabin 2017). In this section, the authors introduce some examples of tactical Meta AI that dynamically adjust the behavior, placement, and other characteristics of NPC according to the position of the character or battle situation.

Deciding Spawning Position

In Left 4 Dead (Booth 2009a, b), players move towards the exit while fighting enemy NPC within a level of intricate terrain. However, Meta AI dynamically spawns several kinds of enemy NPC and weapon items in order to realize unexpected game play that can be repeated many times. For example, the majority of enemies, which are called mob, spawn in areas close behind the player and are not directly visible. Meanwhile, boss enemies are spawned in areas that are close to the player and are not directly visible on the player's predicted path of travel (referred to as "Golden path") (Fig. 3) (Jack and Vehkala 2013). In order to realize such spawning, it is necessary to dynamically analyze the positional relationship between the terrain and the player. Left 4 Dead models terrain information for the Meta AI. First, the terrain is divided into a number of subareas. Then information for each subarea for the remaining distance (flow distance) to the exit is embedded using a navigation mesh. Next, the subarea around the player is dynamically calculated. This is called an active area set (AAS) and



Meta Artificial Intelligence and Artificial Intelligence Director, Fig. 3 An example of enemy spawning by Meta AI. Spawning areas are close to the Golden path and invisible by the player

signifies the entire area to be handled by the Meta AI. Combining AAS and flow distance makes it possible to easily and dynamically calculate places suitable for spawning enemies and items.

Combination with Procedural Level Generation

A similar mechanism is introduced in Warframe (Brewer et al. 2013; Brewer 2014), but in contrast to Left 4 Dead, levels are automatically generated. Therefore, an influence map is used to analyze the movement status of players instead of flow distance. Using the position of a player as a heat source, the temperature of the areas surrounding the player are matched to that heat source producing areas where the temperature rises or falls as the player moves. The area where the temperature rises is regarded as the destination to which the player is heading and in which enemies spawn and the area where the temperature falls is regarded as the place from which the player moves away and enemies there are stopped or deleted.

Natural Cooperating

Meanwhile, in the Meta AI of Final Fantasy XV (Tabata 2016) attention is given to the behavior of ally NPCs (Miyake 2018). When a player and three ally NPCs fight together, the Meta AI analyzes the battle situation and directs an appropriate ally NPC to help the player when in a difficult situation or to follow when the player is running away. This avoids unnatural behaviors such as three allies suddenly coming to help the player all at once and realizes a more natural cooperative behavior.

Noncombat Meta AI

In this section, the authors describe cases of Meta AI with a focus on elements not directly related to combat scenes.

In games with very extensive levels, which are called open worlds, it is difficult for a game creator to appropriately arrange all events in advance. Accordingly, in Far Cry 4 (Hutchinson and Méthé 2014), Meta AI is utilized as an encounter manager and objects are arranged so that various things occur as emergent events based on "location and area," "time of day and weather," "frequency," "priority and probability," and other factors (Varnier 2014). As a result, events such as a soldier and an elephant starting to battle and the elephant overturning a jeep occur irrespective of the player's behavior. Moreover, objects such as prisons and animals are dispersed to have a density that results in players encountering events at an appropriate frequency. In addition, by world profiling and adaptive spawning, the number of scavenger animals is increased when there is a big battle.

In Assassin's Creed: Origins (Guesdon and Ismail 2017), Meta AI was utilized in order to make maximum use of limited resources in a vast terrain and at the same time to make the characters feel as realistic as possible (Lefebvre 2018). Objects in games are broadly divided into two types, moving objects (dynamic objects) such as animals and vehicles and nonmoving objects (static objects) such as bases and garages. For efficient searching, in Assassin's Creed: Origins, dynamic objects can be optimally arranged by dividing the game environment according to invisible destination objects called "station" and "child position." Stations own some child positions, and unoccupied stations are selected by a dynamic object such as a character. At this time, the density of objects is controlled with uniformly sized cells dividing the level. The numbers of dynamic objects existing in one cell are managed simultaneously by Meta AI.

Conclusion and Discussion

In this entry, the authors explained Meta AI, which is an AI that controls the entire game. They classified and explained the two types of combat Meta AI: pacing Meta AI, which controls pacing according to the progress of the game, and tactical Meta AI, which controls spatial tactical behavior. In addition, they explained that the occurrence of events during the game and the arrangement of objects, and other game elements were controlled by noncombat Meta AI. In this section, they conclude the entry by considering

the direction of the future development of Meta AI.

Important functions of Meta AI include (1) understanding the player and the game situation and (2) controlling the contents of the game.

For understanding the player and the game situation, algorithms to calculate the state (intensity) of the player from the data obtained from the game controller input are built ad hoc; however, it is costly to construct the model this way and difficult to ensure accuracy. In recent years, there have been many extensive collections of large-scale game play data using telemetry and their utilization is progressing in visualization of data (Pascale 2016), game balance adjustment (Mouret and Athanassoff 2018), and cheat detection by deep learning (McDonald 2018). Furthermore, approaches to measure the physiological information of players (biofeedback with respect to the game) and more direct estimation of the player's psychological state are promising. For example, Ambinder created a version of Meta AI in Left 4 Dead 2 in which the player's skin conductance level (SCL) was used as the intensity. In a comparative experiment with conventional versions, it was found that the version using biofeedback had higher player satisfaction (Ambinder 2011). It is expected that Meta AI will be able to acquire more useful information by developing methods to increase the amount, quality, and processing of data in the future.

For controlling of the game contents, integration with procedural content generation (PCG) technology is considered important. By using PCG, Meta AI will be able to create the game worlds as well as control the existing game world. For example, PCG is useful to make unique experience to each player because it can change games dynamically. However, PCG technology needs the reference parameter for deciding how to change game contents for each player. If Meta AI guesses the player is angry and it wants the player to become more excited, Meta AI may ask the procedural music system to make the BGM more spectacular and may ask the procedural conversation system to make the enemy's dialogue to fuel the player's excitement. Many PCG technologies have been proposed for every possible component in the game, such as game rules, stories, quests, terrain, music, and others. (Shaker et al. 2016; Short and Adams 2017). In addition, in the game industry, the proliferation of procedural techniques is proceeding in many titles, including Warframe and Far Cry 4 as was previously discussed, and No Man's Sky (Murray et al. 2016). By combining Meta AI and procedural technology, it is possible to realize a different procedural generation of the gaming experience for each player.

In this way, the capabilities of Meta AI to realize more interesting games are dramatically increasing. Designing interesting games by utilizing these technologies will be a challenging future work. Additionally, the importance of developing Meta AI technology in both theory and practice is likely to increase further.

Cross-References

- ▶ Character Artificial Intelligence
- ▶ Navigation Artificial Intelligence

M

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Microscopic Simulation

▶ Crowd Evacuation Using Simulation Techniques

Mindfulness

▶ Mindfulness, Virtual Reality, and Video Games

Mindfulness, Virtual Reality, and Video Games

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Synonyms

Mindfulness; Video games; Virtual reality

Definition

Virtual reality (VR) is "A high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels" (Burdea Grigore and Coiffet 1994).

Mindfulness is defined as the intentional paying attention to the present moment (Kabat-Zinn and Hanh 2009).

Introduction

Mindfulness is characterized by positive emotional states and well-being (Brown and Ryan 2003), and it is researched in many contexts such as health, business, and education (Aviles and Dent 2015). Mindfulness results in being more sensitive to the environment and more open to new information (Langer and Moldoveanu 2000a, b). With the advent of virtual reality and wide use of digital applications, the research on mindfulness in virtual reality and other digital applications is also gaining importance.

There is already a considerable amount of applications in the mobile market targeting solely mindfulness, which have variety of features, support different platforms, and have free or paid versions (Plaza et al. 2013). These interactive applications are mostly used as support tools for the nurturing of mindfulness (Sliwinski et al. 2017). Although more research is needed on the interaction between technology and mindfulness, research shows that mobile-based electronic interventions for mindfulness is potentially effective for stress reduction (Lyzwinski et al. 2017).

Mindfulness in Serious Virtual Reality Applications

There are several studies which show that virtual reality systems and their applications help inducing mindfulness or increase people's mindfulness skills, which in return leads to improved well-being. For instance, augmenting mindfulness in chronic pain patients by the use of a virtual reality system was found to be effective in reducing chronic pain (Gromala et al. 2011). In another study, using virtual reality was shown to be more effective than nonvirtual reality condition in people's learning of mindfulness-based stress reduction (Gromala et al. 2015). Similarly, virtual reality supported mindfulness meditation environments were shown to increase mindfulness skills and psychological well-being (Crescentini et al. 2016). In a case study it was shown that virtual reality-supported mindfulness intervention decreases negative feelings along with urges to commit suicide or self-harm (Nararro-Haro et al. 2016). Other attempts include developing virtual reality systems that aim to improve mindfulness with enjoyable experiences (Amores et al. 2016) and virtual reality systems that are combined with neurofeedback to provide deep relaxation, presence and deep levels of meditation (Kosunen et al. 2016).

Mindfulness in Digital Games

Games may be considered at the intersection of technology and mindfulness, in the sense that they may provide full immersion and engagement for the player leaving little to no cognitive room for worrying or other thoughts (Sliwinski et al. 2017). Although application of mindfulness to the digital games context is relatively new, there are a few studies that incorporate mindfulness theory to video game research. Some of these studies approach the topic from a theoretical perspective, and mainly examine the relation between mindfulness and other user experience constructs. For instance, one study showed that mindfulness was positively associated with frequency of game play, length of game play sessions, total number of games played, and the age begun gaming (younger meaning higher scores) (Gackenbach and Bown 2011). Another study investigated the relationship between social anxiety and state mindfulness in online first person shooter (FPS) games (Gavriloff and Lusher 2015). It was found that more socially anxious players were less mindful in the game. Finally, a project shows that how an innovative use of *Minecraft* with mindfulness

principles may contribute to digital story telling (Butler et al. 2016).

There are also other studies, which approach video games as tools for improving mindfulness. For instance, researchers provided several examples for how digital games can improve mindfulness (Sliwinski et al. 2015). Another study describes how procedural content generation-driven games may increase mindfulness of the players and help learning (Smith and Harteveld 2013).

Although scarce, there is also some research on mindfulness and virtual reality games. For instance, one study examined whether a gamified virtual reality system helps gamers learn about mindfulness practices (Choo and May 2014). Another study explains the design of a virtual reality game to help people practice breathing exercises and mindfulness (Patibanda et al. 2017).

Conclusion and Discussion

Taken together, these studies show that there is potential for use of virtual reality in improving mindfulness and wellbeing. Although mindfulness in virtual reality and games appear to be separate lines of research, it is likely that these lines of research will intersect in future.

Mindfulness in computing is a relatively fresh research area with limited number of studies, and the literature on mindfulness in virtual reality games is even scarcer. Thus, more research is needed to understand the processes related to mindfulness in virtual reality and other digital applications. The use of neurofeedback in mindfulness-related virtual reality gaming looks promising for future applications. From a theoretical perspective, the associations between mindfulness and long-studied phenomena such as immersion, flow, and engagement in virtual reality domain might also provide interesting future research directions. However, the use of virtual reality is not widespread as of the time of this writing. Moreover, to the best of our knowledge there are no studies that examine the acceptance or long-term adoption of these systems. Thus, research on the long-term acceptance of virtual reality systems might be needed before delineating the processes about mindfulness in virtual reality.

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Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems

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Synonyms

Linear solving of Apollonius problem; Linear solving of Dupin problem

Definitions

Introduction of Minkowski-Lorentz spaces to simplify Euclidean 2- or 3-dimensional problems.

Introduction

The Apollonius problem is the determination, in a plane, of a circle tangent to three given geometric circles which corresponds to $2^3 = 8$ Apollonius cases using oriented circles. The use of the Minkowski-Lorentz space permits to choice one over eight cases. Moreover, it generalizes when an oriented circle becomes an oriented line, the new number of solutions is given using the same algorithm whereas the new number of solutions is multiplied by 4 in the usual Euclidean affine space. The centers of the circles tangent to two given circles are on a conic. So, solving one of the Apollonius problems (with oriented circles) leads to the computation of the intersection of two conics whereas the problem is linear on the circles

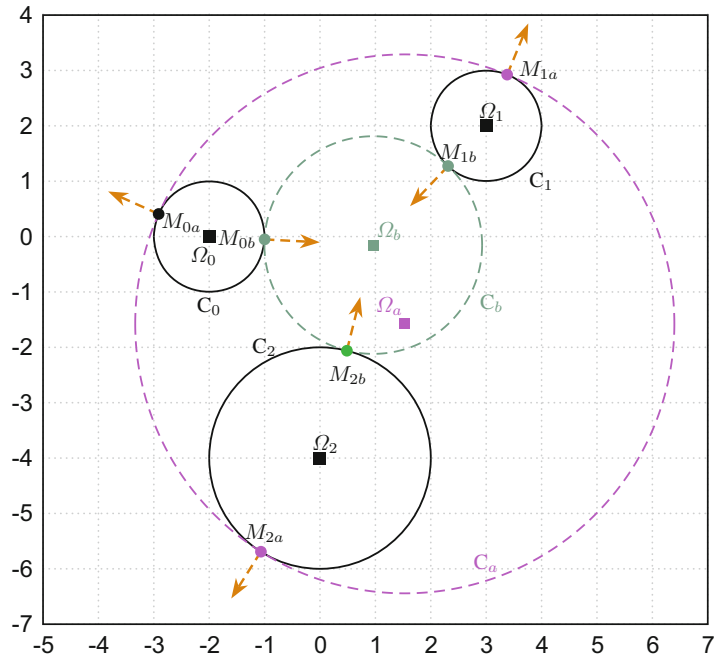
space Λ^3 in the Minkowski-Lorentz space $L_{3,1}$. The Dupin problem is the determination of a surface tangent to three given oriented spheres in $\mathcal{E}_3$. The surface is called a Dupin Cyclide (Darboux 1873, 1887, 1917; Dupin 1822; Dutta et al. 1993; Forsyth 1912; Garnier 2007; Pratt 1990, 1995); its degree is at most 4. To determine the Dupin cyclide, the computation of the two Dupin cyclide principal circles in a plane is necessary. Then, to solve Dupin problem leads to solve the Apollonius problem. One can define a Dupin cyclide as a canal surface in two different equivalent ways. A Dupin cyclide is the envelop of a one-parameter family of oriented spheres centered on a conic (Druoton 2013; Druoton et al. 2013a, 2014; Forsyth 1912; Langevin et al. 2015). As a cubic Dupin cyclide is the envelop of one-parameter family of oriented spheres centered on a parabola, the authors generalize and solve this problem in $\mathcal{E}_2$ and $\mathcal{E}_3$ in section "Family of $n-1$-Spheres Centered onto a Parabola of $\mathcal{E}_n$". To simplify the solving of these problems, the authors use the Minkowski-Lorentz space (Bécar et al. 2016; Druoton et al. 2013b; Garnier and Bécar 2017; entry "▶ Theory of Minkowski-Lorentz Spaces"; Garnier et al. 2017, 2018; Garnier and Druoton 2013)

$n-1$-Spheres Tangent to Three Given $n-1$-Spheres

In this section, the authors consider three oriented $n-1$-spheres, and the goal is to determine the oriented $n-1$-spheres tangent to the three aforementioned oriented $n-1$-spheres. If $n = 2$ (resp. $n = 3$), this problem is known as Apollonius problem (resp. Dupin problem). Using Minkoswki-Lorentz space, the Algorithm 1 permits to resolve these problems.

One can note that all formulas in (1) are linear and force that the $n-1$-spheres to have the same orientation at the tangency points. Formula (2) permits to find the representation of the $n-1$-spheres on Λ^{n+1}.

Each equation given in Formula (1) defines a hyperplane in the Minkoswki-Lorentz space. The dimension of each hyperplane is $n + 1$, and the



Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Fig. 1 Solution of the Apollonius problem in $\mathcal{E}_2$ when all the radius ρ_0, ρ_1, and ρ_2 are nonnegative. The radii of the circles which are solutions of our problem have not the same sign; ρ_a (resp. ρ_b) is nonnegative (resp. nonpositive)

dimension of the set defined by Formula (1) is $n-1$. Using $\mathcal{E}_2$ (resp. $\mathcal{E}_3$), the authors obtain a line (resp. a two-plane), and the intersection between this line and A^{n+1} is two points (resp. a circle for the Lorentz form or a parabola isometric to a line).

Algorithm 1: Solving of Apollonius-Dupin Problems

Input: Three oriented $n-1$-spheres S_0, S_1, and S_2 of $\mathcal{E}_n$, $n \in \{2,3\}$

1. For i in $[\![0, 2]\!]$, computation of the representation σ_i in $L_{n+1,1}$ of the oriented $n-1$-sphere S_i

2. Determination of σ by

$$\begin{cases} \overrightarrow{O_{n+2}\sigma} \cdot \overrightarrow{O_{n+2}\sigma_0} = 1 \\ \overrightarrow{O_{n+2}\sigma} \cdot \overrightarrow{O_{n+2}\sigma_1} = 1 \\ \overrightarrow{O_{n+2}\sigma} \cdot \overrightarrow{O_{n+2}\sigma_2} = 1 \end{cases} \tag{1}$$

and

$$\overrightarrow{O_{n+2}\sigma^2} = 1 \tag{2}$$

3. For i in $[\![0, 2]\!]$, from the solutions σ_s of the equations given by Formulas (1) and (2), computation of tangency points using the light-like vectors $\overrightarrow{\sigma_s\sigma_i}$

4. Computation of the oriented $n-1$-spheres S_s of $\mathcal{E}_n$ from the solutions σ_s of the equations given by Formulas (1) and (2)

Output: A family of oriented $n-1$-spheres tangent (with the same orientation) to S_0, S_1, and S_2

Linear Solving of Apollonius Problem

The Figs. 1 and 2 shows a solution of the Apollonius problem in $\mathcal{E}_2$ with the same geometric circles (Table 1).

In Fig. 1, Formulas (1) and (2) lead to

$$\begin{cases} \sigma_a\left(\dfrac{32\sqrt{6061}-1058}{6975}, \dfrac{12\sqrt{6061}-203}{2325}, \dfrac{-6\sqrt{6061}-286}{2325}, \dfrac{-8\sqrt{6061}-278}{465}\right) \\ \sigma_b\left(\dfrac{-32\sqrt{6061}-1058}{6975}, \dfrac{-12\sqrt{6061}-203}{2325}, \dfrac{6\sqrt{6061}-286}{2325}, \dfrac{8\sqrt{6061}-278}{465}\right) \end{cases}$$

which define the circles C_a and C_b of centers Ω_a and centers Ω_b and of radii ρ_a and ρ_b. The coordinates of Ω_a are

$$\left(\frac{4\sqrt{6061}+1363}{1094}, \frac{-5\sqrt{6061}-473}{547}\right) \simeq (1.53053902924, -1.5763475731)$$

whereas the coordinates of Ω_b are

$$\left(\frac{-4\sqrt{6061}+1363}{1094}, \frac{5\sqrt{6061}-473}{547}\right) \simeq (0.961234279272, -0.1530856993)$$

The radius of C_a is

$$\rho_a = \frac{48\sqrt{6061}+1587}{1094} \simeq 4.86646835086$$

whereas the radius of C_b is

$$\rho_b = \frac{-48\sqrt{6061}+1587}{1094} \simeq -1.96518864336$$

The light-like vectors which define the points of tangency are defined in Table 2.

In the Fig. 1, the radius ρ_2 is changed into its opposite, and the Fig. 2 shows the solution of this new Apollonius problem in $\mathcal{E}_2$.

Formulas (1) and (2) lead to

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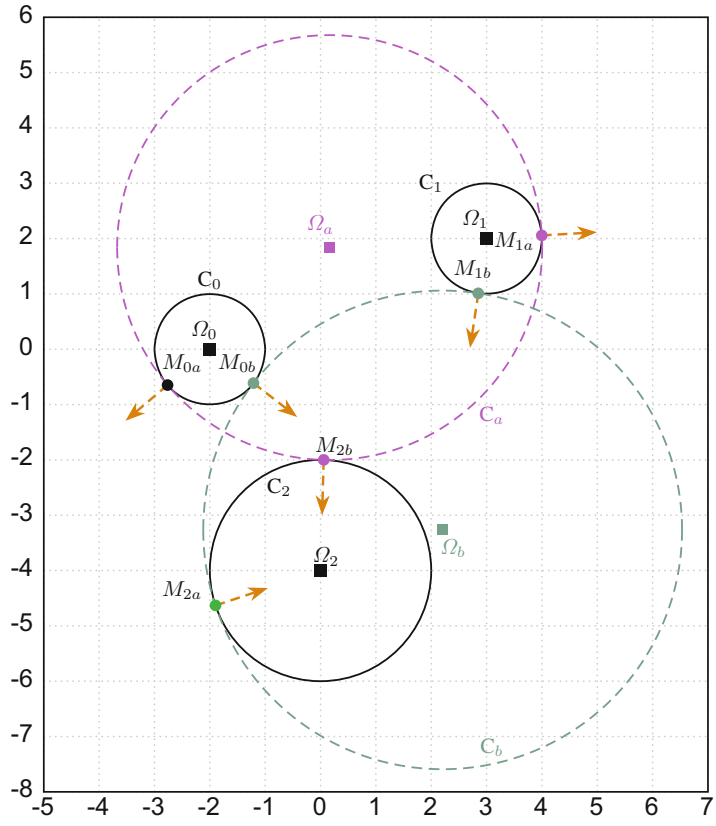

Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Fig. 2 Solution of the Apollonius problem in $\mathcal{E}_2$, the radius ρ_2 used in Fig. 1, is changed into its opposite

$$\begin{cases} \sigma_a\left(\dfrac{32\sqrt{319}+34}{2325}, \dfrac{12\sqrt{319}-181}{775}, \dfrac{-6\sqrt{319}+478}{775}, \dfrac{-8\sqrt{319}-86}{155}\right) \\ \sigma_b\left(\dfrac{-32\sqrt{319}+34}{2325}, \dfrac{-12\sqrt{319}-181}{775}, \dfrac{6\sqrt{319}+478}{775}, \dfrac{8\sqrt{319}-86}{155}\right) \end{cases}$$

which define the circles C_a and C_b of centers Ω_a and centers Ω_b and of radii ρ_a and ρ_b. The coordinates of Ω_a are

$$\left(\frac{-4\sqrt{319}+83}{70}, \frac{\sqrt{319}-5}{7}\right) \simeq (0.165, 1.837)$$

whereas the coordinates of Ω_b are

$$\left(\frac{4\sqrt{319}+83}{70}, \frac{-\sqrt{319}-5}{7}\right) \simeq (2.206, -3.266)$$

The radius of C_a is

$$\rho_a = \frac{16\sqrt{319}-17}{70} \simeq 3.840$$

whereas the radius of C_b is

$$\rho_b = \frac{-16\sqrt{319}-17}{70} \simeq -4.325$$

The light-like vectors which define the points of tangency are defined in Table 3.

Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Table 1 Characteristic of circles in the Apollonius problem in Figs. 1 and 2 and their representations on $\mathcal{A}^3$

Name	Center	Radius	On $\mathcal{A}^3$	Figure
C_0	$\Omega_0(-2, 0)$	$\rho_0 = 1$	$\overrightarrow{O_4\sigma_0} = \overrightarrow{e_o} - 2\overrightarrow{e_1} + \frac{3}{2}\overrightarrow{e_\infty}$	Figures 1 and 2
C_1	$\Omega_1(3, 2)$	$\rho_1 = 1$	$\overrightarrow{O_4\sigma_1} = \overrightarrow{e_o} + 3\overrightarrow{e_1} + 2\overrightarrow{e_2} + 6\overrightarrow{e_\infty}$	Figures 1 and 2
C_2^+	$\Omega_2^+(0, -4)$	$\rho_2^+ = 2$	$\overrightarrow{O_4\sigma_2^+} = \frac{1}{2}\overrightarrow{e_o} - 2\overrightarrow{e_2} + 3\overrightarrow{e_\infty}$	Figure 1
C_2^-	$\Omega_2^-(0, -4)$	$\rho_2^- = -2$	$\overrightarrow{O_4\sigma_2^-} = -\frac{1}{2}\overrightarrow{e_o} + 2\overrightarrow{e_2} - 3\overrightarrow{e_\infty}$	Figure 2

Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Table 2 Determination of the tangency points in the Apollonius problem in Fig. 1

Circles	Light-like vectors	Point of tangency
C_0 and C_a	$\overrightarrow{m_{0a}} \simeq (1, -2.913, 0.408, 4.326)$	$M_{0a} \simeq (-2.913, 0.408)$
C_1 and C_a	$\overrightarrow{m_{1a}} \simeq (1, 3.380, 2.925, 9.990)$	$M_{1a} \simeq (3.380, 2.925)$
C_2 and C_a	$\overrightarrow{m_{2a}} \simeq (1, -1.068, -5.691, 16.764)$	$M_{2a} \simeq (-1.068, -5.691)$
C_0 and C_b	$\overrightarrow{m_{0b}} \simeq (1, -1.001, -0.051, 0.503)$	$M_{0b} \simeq (-1.001, -0.051)$
C_1 and C_b	$\overrightarrow{m_{1b}} \simeq (1, 2.312, 3.485, 3.485)$	$M_{1b} \simeq (2.312, 3.485)$
C_2 and C_b	$\overrightarrow{m_{2b}} \simeq (1, 0.485, -2.060, 2.239)$	$M_{2b} \simeq (0.485, -2.060)$

Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Table 3 Determination of the tangency points in the Apollonius problem in Fig. 2

Circles	Light-like vectors	Point of tangency
C_0 and C_a	$\overrightarrow{m_{0a}} \simeq (1, -2.762, -0.647, 4.025)$	$M_{0a} \simeq (-2.762, -0.647)$
C_1 and C_a	$\overrightarrow{m_{1a}} \simeq (1, 3.998, 2.057, 10.110)$	$M_{1a} \simeq (3.998, 2.057)$
C_2 and C_a	$\overrightarrow{m_{2a}} \simeq (1, 0.057, -2.001, 2.003)$	$M_{2a} \simeq (0.057, -2.001)$
C_0 and C_b	$\overrightarrow{m_{0b}} \simeq (1, -1.210, -0.613, 0.920)$	$M_{0b} \simeq (-1.210, -0.613)$
C_1 and C_b	$\overrightarrow{m_{1b}} \simeq (1, 2.851, 1.011, 4.575)$	$M_{1b} \simeq (2.851, 1.011)$
C_2 and C_b	$\overrightarrow{m_{2b}} \simeq (1, -1.900, -4.631,)$	$M_{2b} \simeq (-1.900, -4.631)$

Figure 3 shows the solution of the Apollonius problem in $\mathcal{E}_2$ when a circle is a hyperplane defined by the point P_0 (−3,0) and the normal unit vector $\overrightarrow{e_1}(1, 0)$ and the radius of C_1 has changed into its opposite, i.e., $\rho_1 = -1$; C_2^+ is kept. The representation of the line is given by

$$\overrightarrow{O_4\sigma_0} = -\overrightarrow{e_1} + 3\overrightarrow{e_\infty}$$

whereas the representation of the circle C_1 is

$$\overrightarrow{O_4\sigma_0} = -\overrightarrow{e_o} - 3\overrightarrow{e_1} - 2\overrightarrow{e_2} - 6\overrightarrow{e_\infty}$$

Formulas (1) and (2) lead to

$$\begin{cases} \sigma_a\left(\frac{-40}{141}, \frac{-7}{47}, \frac{-20}{47}, \frac{66}{47}\right) \\ \sigma_b(0, -1, 0, -2) \end{cases}$$

which define the circle C_a of center Ω_a and of radius ρ_a and the hyperplane C_b defined by the point Ω_b (2,0) and the unit vector $\overrightarrow{e_1}$. The coordinates of Ω_a are

$$\left(\frac{21}{40}, \frac{3}{2}\right) \simeq (0.525, 1.5)$$

and the radius of C_a is

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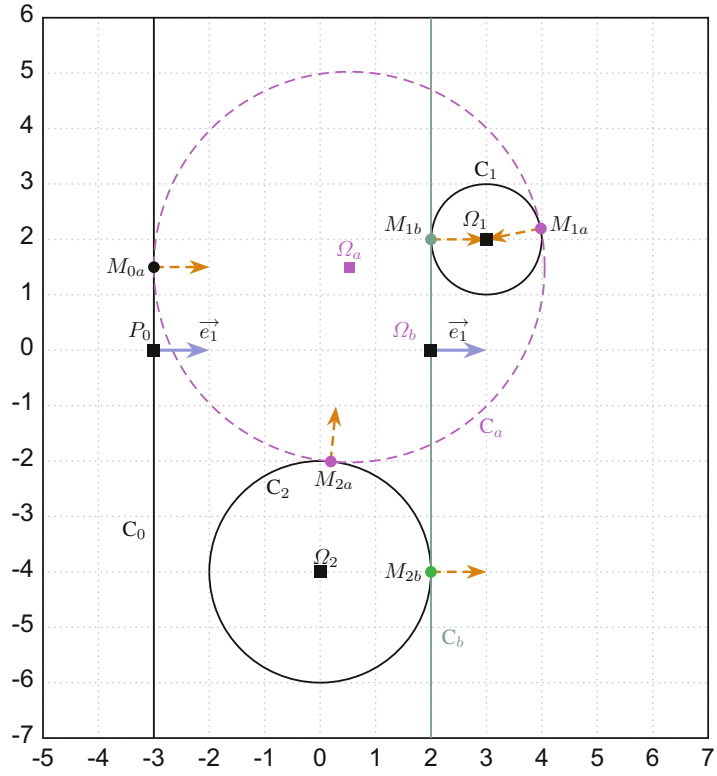


Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Fig. 3 Solution of the Apollonius problem in $\mathcal{E}_2$, the authors change the circle S_0 used in Fig. 1 into a hyperplane (a line)

Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Table 4 Determination of the tangency points in the Apollonius problem in Fig. 3

Circles	Light-like vectors	Point of tangency
C_0 and C_a	$\overrightarrow{m_{0a}} \simeq \left(1, -3, \frac{3}{2}, \frac{45}{8}\right)$	$M_{0a} \simeq \left(-3, \frac{3}{2}\right)$
C_1 and C_a	$\overrightarrow{m_{1a}} \simeq (1, 3.980, 2.198, 10.337)$	$M_{1a} \simeq (3.980,\ 2.198)$
C_2 and C_a	$\overrightarrow{m_{2a}} \simeq (1, 0.190, -2.009, 2.036)$	$M_{2a} \simeq (0.190,\ -2.009)$
C_0 and C_b	$\overrightarrow{m_{0b}} = \overrightarrow{e_\infty}$	$M_{0b} = \infty$
C_1 and C_b	$\overrightarrow{m_{1b}} \simeq (1, 2, 2, 4)$	$M_{1b} \simeq (2,\ 2)$
C_2 and C_b	$\overrightarrow{m_{2b}} \simeq (1, 2, -4, 10)$	$M_{2b} \simeq (2,\ -4)$

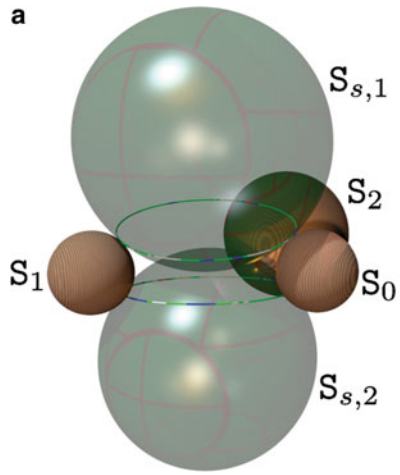
$$\rho_a = \frac{-141}{40} \simeq -3.525$$

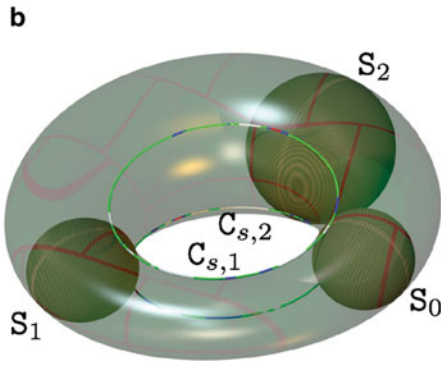
The light-like vectors which define the points of tangency are given in Table 4. One can note that if the authors change the orientation of the line C_0, the solution is two circles with nonnegative radius. The Dupin problem is now on consideration.

Linear Solving of Dupin Problem

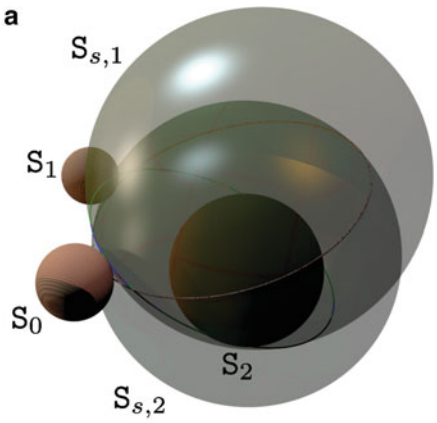
The authors replace the circles given in Table 1 by spheres, and the authors add a zero as last component: the centers of the spheres belong to

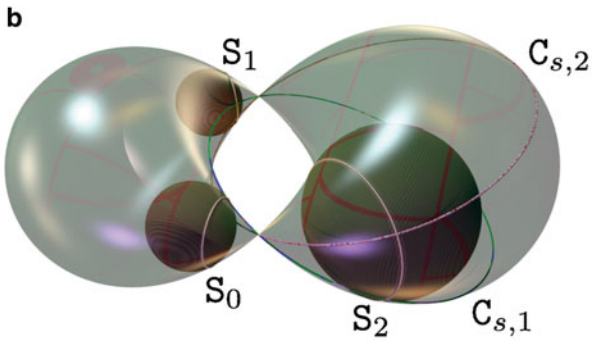
the plane of equation $z = 0$ in $\mathcal{E}_3$. The representations of these spheres on Λ^4 are given in Table 1; the expressions on Λ^3 and Λ^4 are the same. The solution of the Dupin problem leads to a cylinder of revolution or a cone of revolution or cubic or quartic surface: the Dupin cyclides (Cayley 1873; Darboux 1887, 1917; Druoton 2013; Druoton et al. 2014; Dupin 1822; Garnier and Bécar 2017; Pratt 1990, 1995). These surfaces are canal surfaces in two ways: the centers of the spheres which define a quartic Dupin cyclide belong to an



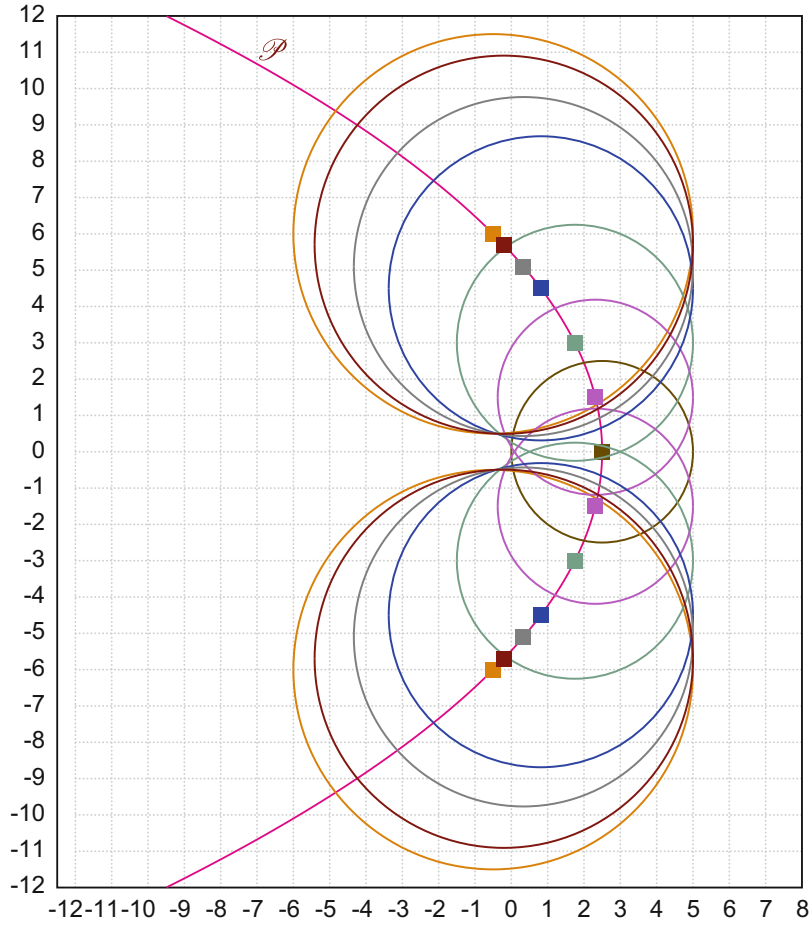


Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Fig. 4 Solution of Dupin problem in $\mathcal{E}_3$ from the Apollonius problem in $\mathcal{E}_2$ given in Fig. 1. (**a**) The three initial spheres S_0, S_1, and S_2, two spheres $S_{s,1}$ and $S_{s,2}$ tangent to the previous spheres, and two characteristic circles. (**b**) The three initial spheres S_0, S_1, and S_2, the quartic ring Dupin cyclide, and two characteristic circles





Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Fig. 5 Solution of Dupin problem in $\mathcal{E}_3$ from the Apollonius problem in $\mathcal{E}_2$ given in Fig. 2. (**a**) The three initial spheres S_0, S_1, and S_2, two spheres $S_{s,1}$ and $S_{s,2}$ tangent to the previous spheres, and two characteristic circles. (**b**) The three initial spheres S_0, S_1, and S_2, the quartic horned Dupin cyclide, and two characteristic circles



Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Fig. 6 The parabola $\mathcal{P}$ and some circles ($n-1$-spheres) of the one-parameter family $\mathcal{F}$ in $\mathcal{E}_2$, $p=-1$, and $q=5$. These circles have been drawn for the values 0, $\pm\frac{1}{4}$, $\pm\frac{1}{2}$, $\pm\frac{3}{4}$, ± 0.85, ± 0.95, and ± 1 in Formulas (3) and (4)

ellipse and a hyperbola; and the centers of the spheres which define a cubic Dupin cyclide belong to two parabolas. Moreover, each sphere of a family of spheres which generates the Dupin cyclide is tangent to the all spheres of the other family.

The circles computed in Figs. 1, 2, and 3 are called principal circles and permit the determination of Dupin cyclides parameters.

From Fig. 1, the parameters of the quartic ring Dupin cyclide are

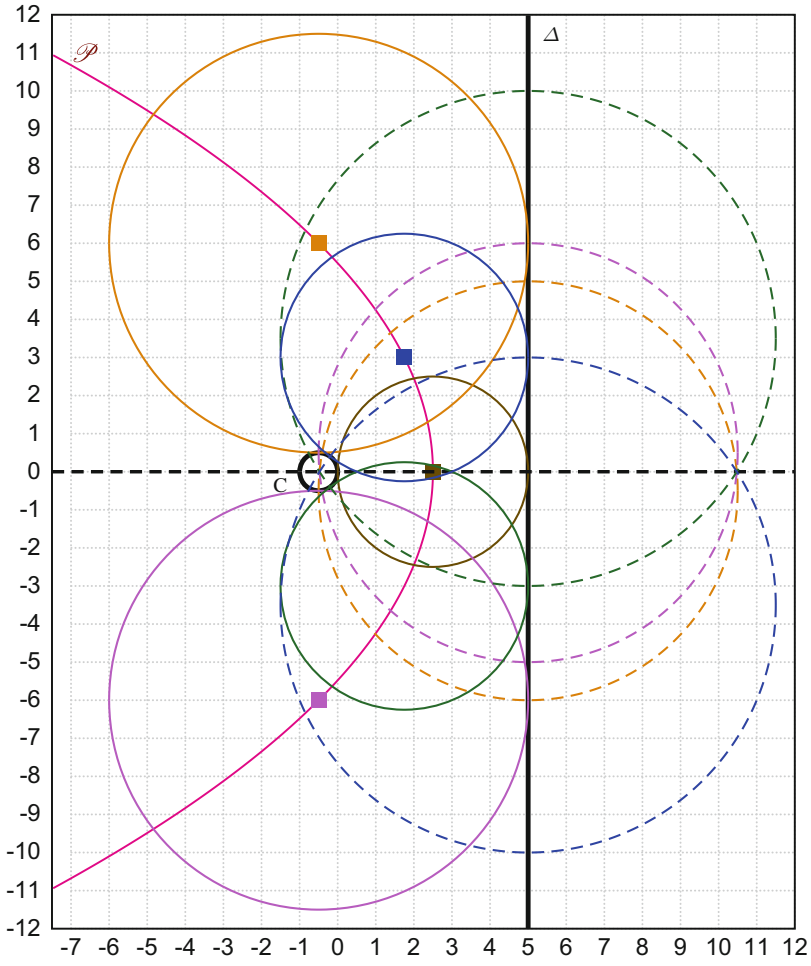
$$(a, c, \mu) \simeq (3.416, 0.766, 1.451)$$

and figure shows the solution of this Dupin problem (Fig. 4).

From Fig. 2, the parameters of the quartic horned Dupin cyclide are

$$(a, c, \mu) \simeq (4.082, 2.748, 0.243)$$

and figure shows the solution of this Dupin problem (Fig. 5).



Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Fig. 7 The parabola $\mathcal{P}$ and some circles ($n-1$-spheres) of the one-parameter family $\mathcal{F}$ and their orthogonal $n-1$-spheres in $\mathcal{E}_2$, $p=-1$ and $q=5$ and the envelope of $\mathcal{F}$ which is the union between a circle C and a line Δ. These circles have been drawn for the values 0, $\pm\frac{1}{2}$, and ± 1 in Formulas (3) and (4)

Family of $n-1$-Spheres Centered onto a Parabola of $\mathcal{E}_n$

Let p et q be two reals such as

$$pq < 0$$

The parabola $\mathcal{P}$ is defined as the set of $\Omega(t)$ defined like this

$$\overrightarrow{O_n\Omega(t)} = \left(\frac{q}{2} + \frac{(p-q)}{2}t^2\right)\overrightarrow{e_1} + (p-q)t\overrightarrow{e_2} \qquad (3)$$

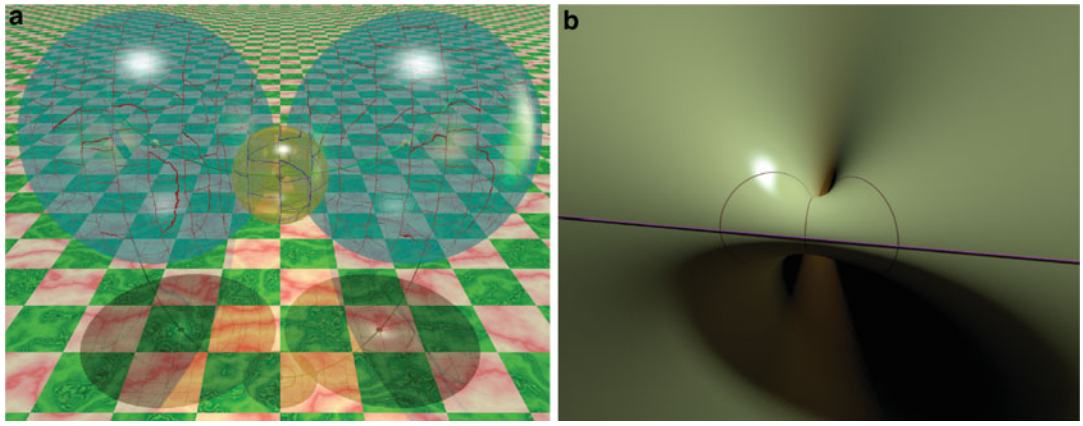
where $t \in \mathbb{R}$.

The one-parameter family $\mathcal{F}$ of oriented n–1-spheres is defined: the centers are $\Omega(t)$, and the radii are

$$\rho(t) = \frac{q-(p-q)t^2}{2}, t \in \mathbb{R} \qquad (4)$$

and the envelope defined by the family $\mathcal{F}$ is computed. Figure 6 shows an example in $\mathcal{E}_2$ with $p=-1$ and $q=5$.

The representation of the family $\mathcal{F}$ in the Minkowski-Lorentz space is



Minkowski-Lorentz Spaces Applications: Resolution of Apollonius and Dupin Problems, Fig. 8 Generation of a cubic Dupin cyclide in $\mathcal{E}_3$. (**a**) The parabola P and three spheres ($n-1$-spheres) of the one-parameter family. (**b**) The cubic Dupin cyclide and three characteristic circles

$$\overrightarrow{O_{n+2}\sigma(t)} = \frac{2}{q-(p-q)t^2}\overrightarrow{e_o} + \frac{t^2p(p-q)}{q-(p-q)t^2}\overrightarrow{e_\infty} + \frac{q+(p-q)t^2}{q-(p-q)t^2}\overrightarrow{e_1} + \frac{2(p-q)t}{q-(p-q)t^2}\overrightarrow{e_2}$$

and the derivative sphere (15) is

$$\overrightarrow{O_{n+2}\,\dot\sigma\,(t)} = \frac{2t(p-q)}{(p-q)^2t^2+q(q-p)}\overrightarrow{e_o} + \frac{pq(p-q)t}{(p-q)^2t^2+q(q-p)}\overrightarrow{e_\infty} + \frac{2t\,q\,(p-q)}{(p-q)^2t^2+q(q-p)}\overrightarrow{e_1} + \frac{(p-q)\,((p-q)t^2+q)}{(p-q)^2t^2+q(q-p)}\overrightarrow{e_2}$$

which generates, it $t \neq 0$, the $n-1$-sphere of center $\dot\Omega(t)$ defined by

$$\overrightarrow{O_n\dot\Omega(t)} = q\overrightarrow{e_1} + \frac{(p-q)t^2+q}{2t}\overrightarrow{e_2}$$

and of radius

$$\dot\rho\,(t) = \frac{\left|(p-q)^2t^2+q(q-p)\right|}{2t(p-q)}$$

and $\dot\sigma\,(0)$ is the representation of the hyperplane defined by the point O_n and the unit normal vector sign $(q(p-q))\,\overrightarrow{e_2}$. Figure 7 shows an example in $\mathcal{E}_2$ with $p=-1$ and $q=5$; the envelope is the circle C and the line Δ.

Figure 8 shows an example in $\mathcal{E}_3$ with $p=-1$ and $q=5$; the canal surface is a cubic Dupin cyclide. Using the construction in the plane of equation $z=0$, the two principal circles which permit the computation of the Dupin cyclide parameter are calculated. Moreover, in this plane, the Figs. 6 and 7 are obtained.

Conclusion

This article presents some applications of the Minkowski-Lorentz space and its interest for computer graphics. In section "*n* – 1-Spheres Tangent to Three Given *n* – 1-Spheres," the representation of spheres in the Minkowski-Lorentz space permits to solve classical geometric problems like Apollonius problems or Dupin problems. First, as the point at infinity is seen as any point, we get a more general solution including spheres and hyperplane. Second, a lot of quadratic computations in the Euclidean space become linear in this space. In section "Family of *n*–1-Spheres

Centered onto a Parabola of $\mathcal{E}_n$," an envelope of a family of oriented circles or spheres is computed.

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Minutiae Extraction

▶ Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features

Mixed Reality

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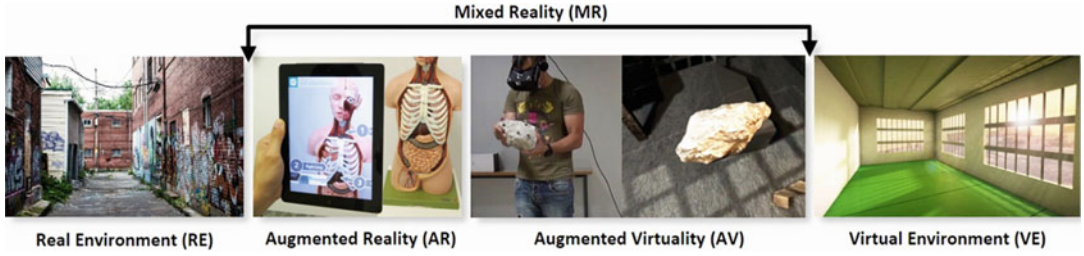
Synonyms

Augmented Reality; Augmented Virtuality; Virtual Environments; Virtual Reality; Virtuality Continuum

Definitions

The Virtuality Continuum represents a scale which extends from the completely Real



Mixed Reality, Fig. 1 Virtuality continuum

Environment (RE) to the completely Virtual Environment (VE) with Mixed Reality (MR) laying in between. MR refers to environments anywhere between the extremes of the Virtuality Continuum, wherein real world and virtual world objects are presented together in a single display. Augmented Reality (AR) superimposes computer-generated objects upon the RE, while Augmented Virtuality (AV) blends real-world elements into the VE. Virtual Reality (VR) refers to entirely synthetic worlds, which may mimic the physical properties of the real world, wherein the user can be totally immersed.

Introduction

The Virtuality Continuum encompasses all possible variations of blending real and virtual elements into a single environment, with the RE and VE laying at the ends of the scale. MR spans between RE and VE, referring to environments which integrate virtual and physical elements within a coherent space (see Fig. 1), with the two most popular MR paradigms being AR and AV (Milgram and Kishino 1994).

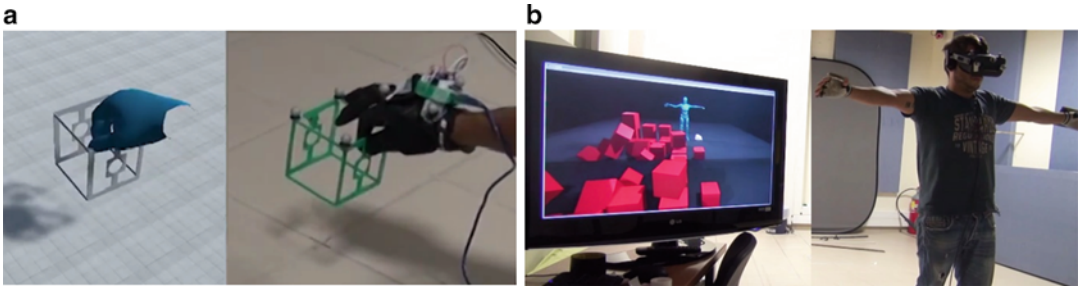
Augmented Reality (AR)

AR applications may be implemented through three different methods. Marker-based AR is based on vision tracking and relies upon the placement of fiducial markers into the RE, which are then tracked via a camera feed, projected onto displays of devices such as smartphones, Head-Mounted Displays (HMDs), or Personal Computers (PC). In marker-based, the RE is streamed through the camera feed and superimposed by virtual elements, based on the location of the fiducial marker (Azuma et al. 2001). Figure 2a shows an example of marker-based AR, using the popular AR development framework Vuforia (https://www.vuforia.com/), where the RE is projected to the user through a web-camera feed and augmented by a 3D model based on the location of a fiducial marker.

Marker-less AR is based on computer vision and motion tracking technology, to accurately place 3D objects on top of the RE which the user sees through the device's camera feed (Azuma et al. 2001). A popular framework for marker-less AR development is ARCore (https://developers.google.com/ar/discover/). ARCore blends virtual objects with the RE, employing (a) motion tracking, to estimate the phone's position and orientation in relation to the world and ensure accurate projection of virtual objects; (b) perception of the environment, to detect the dimensions and positioning of flat horizontal surfaces so as to place virtual objects on them; (c) light estimation, to properly estimate the RE's light conditions, thus overlay the virtual objects upon the RE with appropriate shadows and lighting (see Fig. 2b).

The third method for realizing AR applications is sensor-based AR, wherein multiple commodity sensors are utilized to extract device's rotation and direction. This information allows the appropriate positioning of virtual elements on top of the RE, which the user sees using the camera feed or see-through capability of the device. Typically, sensor-based AR utilizes GPS to acquire user location, providing accurate outdoors positioning with respect to virtual elements, which are often bound to real locations (Zhou et al. 2008). Figure 2c illustrates an example of sensor-based AR with GPS integration, created with the AR

Mixed Reality, Fig. 2 (**a**) Marker-based AR; (**b**) marker-less AR; (**c**) sensor-based AR with GPS integration



Mixed Reality, Fig. 3 (**a**) Using real hands and objects into the VE; (**b**) full body representation into VE using motion capture

application development framework Wikitude (https://www.wikitude.com/), where the RE is superimposed with virtual elements based on the device's rotation, direction, and location.

The outspread of camera- and sensor-enabled smartphones and HMDs has resulted in the establishment of AR as the most widespread type of MR, with numerous applications in a variety of fields, such as gaming, tourism, military, and medicine (Azuma et al. 2001).

Augmented Virtuality (AV)

AV refers to the augmentation of the VE with real elements, aiming at enriching the overall user experience (Schnabel et al. 2007). AV allows users to navigate within a completely synthetic world, enabling interaction with either fictional or real objects (Ternier et al. 2012). AV projects developed in the past are scarce and have mostly focused on embedding real-world camera feeds and a few user movements into the VE (Regenbrecht et al. 2004).

However, recent technological advances, such as data gloves (Silva et al. 2013) and motion capture (Chan et al. 2011), fueled the development of AV worlds, facilitating the integration of real elements into the VE. Figure 3a demonstrates an AV example where a data-glove, powered by Arduino (https://www.arduino.cc/), provides information of the user's finger position and rotation, while the hand's overall position, along with the one of another real object, is tracked using a motion capture system by Vicon (https://www.vicon.com/). This implementation enables concurrent interaction with both real and virtual objects. Figure 3b illustrates another example of AV, wherein the motion capture system by Vicon is integrated with an Oculus Rift (https://www.oculus.com/rift/) HMD to transfer the full body movement of a user from the RE to the VE in real time.

Conclusion

In 1994, Milgram and Kishino foresaw that delimiting AR and AV worlds would be hard, as future technological advances would allow seamless blending between RE and VE (Milgram and Kishino 1994). Their prediction has been confirmed to a certain degree, since the predominance of either RE or VE in recent AR and AV worlds is equivocal. MR remains the most widespread term used to describe the area between RE and VE and represents a particularly promising field of research and commercial exploitation.

Cross-References

- 3D Puzzle Games in Extended Reality Environments
- Augmented Reality for Maintenance
- Augmented Reality Entertainment: Taking Gaming Out of the Box
- Everyday Virtual Reality
- Experiential Media: Using Machine Vision and Sensor-Input to Create Dynamic Real-Time Generated Media
- History of Augmented Reality
- Interaction with Mobile Augmented Reality Environments
- Key Early Verticals: Challenges and Limitations in Implementation of Augmented Reality
- Making Virtual Reality (VR) Accessible for People with Disabilities
- Mixed Reality
- Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
- Origin of Virtual Reality
- Shadow Shooter: All-Around Game with e-Yumi 3D
- Virtual Reality and Robotics

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Mixed Reality and Immersive Data Visualization

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Synonyms

Augmented reality; Holography; Immersion; Information visualization; User experience; Virtual reality

Definitions

Mixed reality is related to the hybrid visualization of virtual objects superimposed in real scenarios with the possibility of interaction with them by the users.

Data visualization places the information/data in focus, distinguishing it from the unnecessary

information and facilitating the understanding of correlated data, thus allowing the recognition of patterns and facilitating inferences about different concepts.

Introduction

Currently, the visualization of information and data can be improved by the use of techniques related to the concepts of mixed reality (MR) and immersive user experience. While the MR is related to the merging of real and virtual worlds to produce new environments and visualizations, the immersive user experience refers to the quality that an interaction offers to the user, allowing him/her to feel connected to the system and being part of the presented data visualization.

MR combines characteristics of virtual reality (VR), augmented reality (AR), and holography. The VR deals with the virtual environment interaction, generated by computer, that allow people to visualize, manipulate, and interact with representations of a three-dimensional (3D) scenario and objects in real time. For this, the user interacts with the VR through specific devices such as the head-mounted display (HMD) or VR glasses, in order to improve the feeling of immersion during the interaction (Milgram and Kishino 1994; Burdea and Coiffet 2003; Bowman et al. 2004; Krevelen and Poelman 2010).

The AR, on the other hand, allows the visualization of virtual objects combined with scenes from real environments with mobile devices such as smartphones and tablets or AR glasses and head-mounted display.

So the real and virtual environments are connected, enriching the real world with computer-generated virtual objects or other technological devices that seem to coexist in the same space and run in real time in an interactive way (Azuma 1997; Azuma et al. 2001; Milgram et al. 1994).

Another way of visualizing and interacting with 3D images is through the concept of holography (Leith 1972; Schnars et al. 2015). A hologram is a 3D image obtained from the projection of light on two-dimensional figures.

From such concepts, the MR works with virtual objects (VR) inserted in real scenes (AR) as part of this universe (holography), allowing the direct interaction of the user with virtual objects with or without the use of specific devices for this purpose, such as HMD or VR/AR glasses.

Besides MR, data (or information) visualization is another important emergent technology. Considering which the amount of data in the world is growing faster than ever before, data visualization techniques help people make sense of the data and turn it into insights (Card et al. 1999; Mazza 2009). In this context, the idea of immersive data visualization is to offer full interaction with the data, allowing easier recognition and retention of patterns (Kreylos et al. 2008; Manning et al. 2008; Han et al. 2012; Donalek et al. 2014; Geryk 2015; Olshannikova et al. 2015).

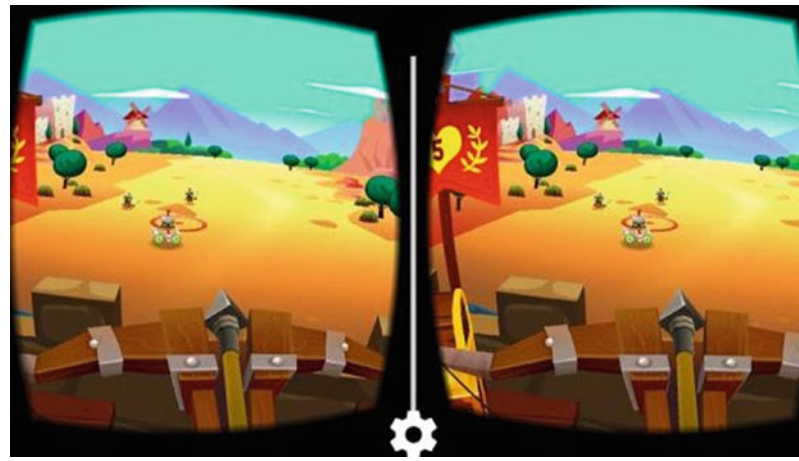
In this context, this article presents and discusses concepts of MR applied to data visualization field in order to improve the analysis by users through an immersive interaction.

Background

According Kim (2005), the VR consists of reproducing a synthetic experience representing a context of virtual simulation to the user. The VR system has three essential components: one or more screens, a set of sensors that detect the movements and stimulate the user, and a mobile device, console, or computer, which controls the whole experience (Fig. 1).

However, one of the major problems of the current VR devices is the motion sickness related to the user's movement in the virtual world and the monitoring of the image displayed on the screen (Hettinger and Riccio 1992). This problem occurs due to the need to generate stereoscopic images (Fig. 2), that is, two scenes being one for each eye in order to produce a high degree of realism in the sensation of depth, which can cause a drop in performance. If the update time is too long, this will cause nausea and/or discomfort.

Mixed Reality and Immersive Data Visualization, Fig. 1 VR glasses with a smartphone inside displaying the video



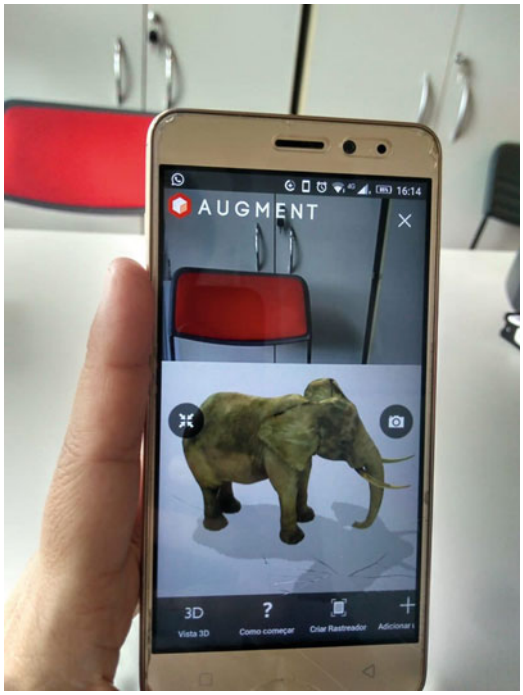
Mixed Reality and Immersive Data Visualization, Fig. 2 VR stereoscopic images from the "Romans From Mars 360" game (Majesco Entertainment 2017)

While VR deals with user immersion in a virtual world, the AR allows the visualization of virtual objects combined with scenes from real environments with mobile devices such as smartphones, tablets, or AR glasses (Fig. 3). AR provides the user an interaction natural and direct with the environment.

Both VR and AR technologies need headwear, eyewear, or mobile device in order to allow the user interaction. The holography, instead, presents the scene or object in real space (floating in midair) without the need for 3D glasses or similar, allowing the viewer to look around objects and see them from a slightly different perspective, as they would in real life. Then, this leads to a more comfortable and naturalistic viewing experience. Examples of techniques for generating holograms include software modeling, particle model, and optical reflection (Collier et al. 1971). Figure 4 presents the optical reflection hologram, a common technique based on a plane screen that reflects the 2D images in a translucent and reflective material in an inverted pyramid format, where the holography forms at its center.

These concepts related to MR are possible to apply to data visualization by promoting such an immersive experience for the user. In this context, visualization is a form of communication that transcends application and technological boundaries because it offers a way to data discovery (Defanti et al. 1989). According to Ware (2008), visualization used to be mental images that people formed while they thought about something, but now the term is related to a graphical representation of some data or concept.

The immersive data visualization should allow the user to analyze the dataset and/or information in order to identify patterns growing, which may be indicative of trends, and the discovery and extraction of new, useful, and interesting knowledge from databases (mainly nonconventional databases) (Marr 2017).



Mixed Reality and Immersive Data Visualization, Fig. 3 AR example of a 3D virtual elephant projected over a real scene generated with Augmented software (Augmented 2018)

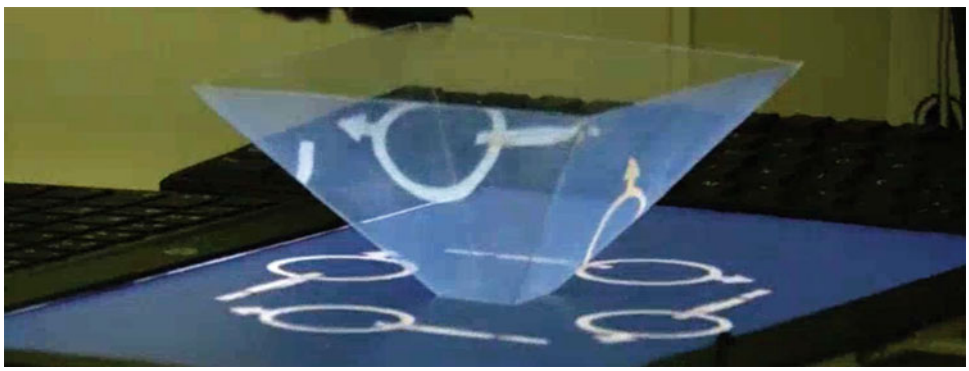
The next section discusses the contribution of the concepts related to MR in order to extract value from the data by increasing the user understanding and improving decision-making capability through immersive interaction.

Data Visualization and Immersive User Experience with Mixed Reality

Bowman and McMahan (2007) already affirmed that the goal of immersive virtual environments was to let the user experience a computer-generated world as if it were real, producing a sense of presence, or "being there," in the user's mind. According to Lemoine et al. (2003), the success of applications involving virtual elements depends on the degree of immersion, comfort, and the nature of the interaction.

Therefore, in MR, the user has the ability to explore the virtual environment and the real world at the same time. The MR combines characteristics of VR with AR through the insertion of virtual objects in the real world and allowing the immersive interaction of the user with such objects, producing new environments in which physical and virtual items coexist and interact in real time (Fig. 5).

There are three basic ideas involving MR and the user experience: (1) immersion, related to the feeling of being inside environments; (2) interaction, which corresponds to the ability of the user to instantly modify the virtual objects projected in



Mixed Reality and Immersive Data Visualization, Fig. 4 3D hologram obtained from a video (Hologram Project by Kiste 2014) of 2D images projected over a translucent and reflective material in pyramid format

Mixed Reality and Immersive Data Visualization, Fig. 5 MR generated with Linq mixed-reality headset (Stereolabs 2017; Steele 2016)

the real world through actions on these; and (3) involvement that is the degree of user motivation with certain activity. These concepts can aid the analysis of data, since they amplify the process of insight, transforming the data and/or amplifying the data as images (Card et al. 1999; Spence 2007).

When an image is analyzed, a cognitive process begins and perceptual mechanisms are activated to identify patterns and segment elements. The correct mapping of data to visualization is crucial, since one can discard relevant information or exceed the amount of irrelevant information (Ware 2004, 2008). Thus, the image should limit the amount of information that the user receives while keeping him/her aware of the total information space and reducing the cognitive effort (Ward et al. 2015; Silva 2017).

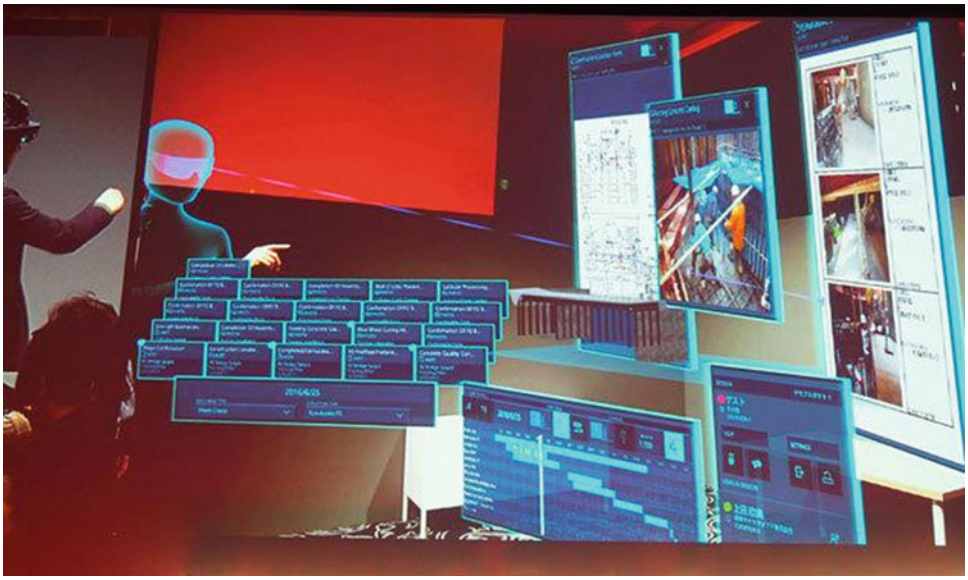
Regarding the common visualization techniques, there are two main problems: defining which visual structures should be used to represent the data and defining the location of such visual structures in the display area (Silva 2017). These problems involve the proposition of adequate visual structures with visual attributes and their location, and reaching a solution involves responding to the following questions:

- What is the problem?
- What is the nature of the data?
- How many dimensions are involved?
- What are the data structures?
- What kind of interaction is required?

Moreover, the classical Shneiderman's visual information-seeking "mantra" (Shneiderman 1996) gives more directions about important features in a visualization: "First, overview, then, zoom and filtering, and finally, details on demand."

Graphs are the most intuitive form of data visualization by their both hierarchical and relational characteristics. An interactive graph or tree solves part of the problem, allowing the user to highlight the information in focus through selection, but the overlapping edges are still a problem. Moreover, as the dataset grows, incorporating new concepts (and their relationships) increases the visualization complexity. Although one can add interaction to solve part of the problem, allowing the user to select the information he/she wants to put into focus, overlapping edges remain a problem.

Besides, data representation in a three-dimensional (3D) space allows the user to navigate through in-depth visual representations, rotating, expanding, and selecting the desired items. However, 3D charts on flat screen can make information difficult to understand and



Mixed Reality and Immersive Data Visualization, Fig. 6 3D hologram obtained from "Holostruction" project generated with HoloLens (Microsoft Asia News Center 2017; Microsoft HoloLens 2017)

compare because these views require the user immersion and depth perception.

In this context, stereo visualization improves user immersion through perception related to the shapes and proportions. The natural interaction with data enhances the intuitive user experience from an extra dimension of information. According Marr (2017), by presenting data that wraps around the user, more than the traditional 3D become available. As well as placement on X, Y, or Z coordinates, data points can be distinguished by size, color, transparency, as well as direction and velocity of movement.

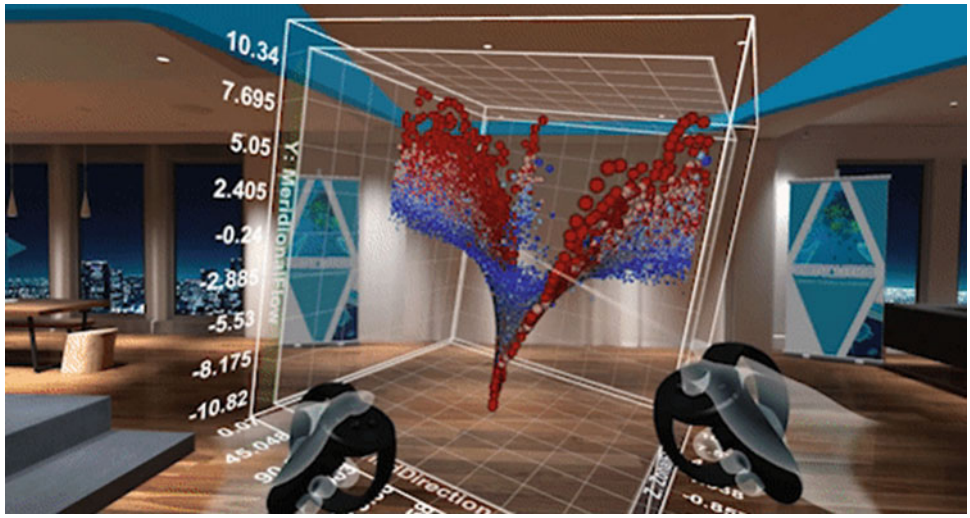
Figure 6 presents an image that applies MR to data visualization through the exhibition of interactive overlaying holograms and enables the user to view and manipulate these within a visible, real-world context.

In relation to data analytics visualization, if the MR techniques are combined with visual analytics, it is possible to amplify the cognition and reduce exploration time of a dataset, allowing the recognition of patterns and facilitating inferences about different concepts. MR and visual analytics can improve both quality and efficiency of data visualization systems, providing semiautomatic means for driving the visual exploration in a immersive way and replacing traditional 2D charts by interactive and immersive 3D colorful visualizations where the user can "dive into" data and see patterns that are not discernible on 2D charts.

Figure 7 presents an image from the Virtualitics (Donalek 2017), an immersive and collaborative data exploration platform that merges artificial intelligence, big data, and MR. In this image, it is possible to visualize a collaborative and customizable shared space to analyze data, build virtual dashboards, and present and discuss insights.

Besides data visualization and analysis, the possibilities of MR applications are extensive as, for example, military drills based on MR will give the army capabilities beyond what the human being possesses today (Fig. 8). They will be able to view information in real time, share it with other comrades, if necessary share their field of vision, add virtual objects to the training combat field, etc.

Education, health, arts and entertainment, architecture and design, and security are areas that will also benefit from MR technology applied to data visualization.



Mixed Reality and Immersive Data Visualization, Fig. 7 3D dashboard of Virtualitics Immersive Platform (Donalek 2017)

Mixed Reality and Immersive Data Visualization, Fig. 8 3D visualization simulations of a Royal Australian Air Force (RAAF) and Department of Defense project that uses HoloLens (Odom 2017)

Conclusion

Over the last decade, there has been a steady increase of data made available in several forms, and efficient methods for data visualization and interaction became necessary in order to facilitate the comprehension of domains represented in diverse systems.

However, it is not simple to create a visualization and interaction that displays effectively all

the information and, at the same time, allows the user to easily perform various operations on the dataset. The MR technology can contribute to these aspects once it replicates and extends natural and physical interaction through advanced interfaces.

MR combines concepts of VR, AR, and holography to promote innovation and improve the user experience in the interaction of these with graphical representations. This is possible due to advances in techniques of computer vision, graphic processing, and rendering, among others. MR applied to data visualization allows an immersive and approximate real-world experience to the user in order to make it difficult to distinguish physical reality from virtual reality.

Cross-References

- ▶ Cognitive Processing of Information Visualization
- ▶ Holography, History of
- ▶ Information Presentation Methods in Virtual Reality

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Mixed Reality Serious Games

► Gamification and Serious Games

Mixed Reality Stories

► Tabletop Storytelling

Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums

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Synonyms

Augmented reality; Cultural heritage; Gamification; Holographic augmented reality; Mixed reality; Storytelling; Virtual reality

Definition

Mixed reality as display technology, gamification as motivational element, and storytelling as interaction metaphor while maintaining the feeling of

presence are identified as key elements for defining the next generation of virtual museums.

Introduction

Storytelling, presence, and gamification are three basic fields that need to be taken into account when developing novel mixed reality applications for cultural heritage, based on the recent renaissance of commercial VR and AR hardware. This survey aims to cover a gap in the bibliography and the last relevant surveys of Papagiannakis et al. (2008), Jung et al. (2011), Foni et al. (2010), and Anderson et al. (2009) which are more than 7 years old, whereas some of these topics are mentioned in several different chapters within Ioannides et al. (2017) but not in single, comparative study. Section "The Role of Storytelling in Cultural Heritage" of this survey covers the state of the art in storytelling for cultural heritage and virtual museums, section "The Role of Presence in Cultural Heritage" the role of presence, and section "The Role of Gamification in Cultural Heritage" the usage of gamification principles. In the last section "Survey of Recent MR Methods for Virtual Museums," a comparison among latest methods in the above areas is presented.

The Role of Storytelling in Cultural Heritage

Storytelling in Museums

Museums have realized the value of storytelling the second half of the twentieth century. Nowadays museums find themselves competing with the large offer of cultural products coming not only from the cultural sector but also from the entertainment industry. Therefore, museums need to differentiate and make their products more appealing and attractive to a variety of audiences. Influenced by the "new museology" concept and the transformation of the museological practice, which refers to a shift in the social roles of museums encouraging new styles of communication and expression, in contrast to the "cultural authority" of museums based on classic, collections-centered models, museums have changed.

Museums can act as primus inter pares (first among equals) and create a direct communication with the visitors, in which museum is the communicator and the visitor is the receiver and vice versa, providing the visitor the opportunity to actively participate in the story. Museums can have a conversation with the visitor, which can share her/his experiences and personal views. To this end, recent AR/VR commercial h/w technological advances enable the use of sophisticated tools to deliver virtual museum stories and information in a number of ways for experience enhancement, knowledge construction, and meaning making (Sylaiou et al. 2009).

Storytelling Using AR and MR (Merging AMI Installations with Mobile Devices and Physical Artifacts Through Stories)

Storytelling in Mixed Reality

Static visualizations have been traditionally employed to support storytelling in the form of text, diagrams, and images. The adoption of dynamic approaches utilizing state-of-the-art 2D and 3D graphics is emerging in an effort to explore the full potential of interactive narration. Rather than simply constituting an additional layer to exhibitions, the enhancement of CH institutions through interactive MR exhibits added value to the overall user experience (Marshall et al. 2016), especially if combined with personalization to each user's interests (Partarakis et al. 2016). Interactive storytelling in MR environments bridges digital and physical information, augmenting the real world and offering interaction which corresponds to the user's actions in the physical space. Storytelling can be employed for associating tangible and intangible information; such an example is Huang and Huang (2013), where the authors compound information for the promotion of indigenous cultural heritage.

Storytelling Authoring

Authoring refers to the process of creating narrations that form a digital story. In terms of authoring, the most common story types are

character-based stories (Cavazza et al. 2002), linear timeline-based stories (Bimber et al. 2003; Drossis et al. 2013b), and ontology-based stories (Casillo et al. 2016). In terms of authoring virtual worlds, Lu et al. (2008) present an editing environment for facilitating the construction of 3D museums. Additionally, narratives description and structuring is also performed using authoring tools. Ardito et al. (2017) create a similar tool for storytelling creation and customization, focusing on the aspects of smart objects integrated in CH installations. Modern cameras are equipped with depth sensing capabilities allowing the real-time scanning of surroundings with sufficient detail. Such cameras are increasingly being adopted by consumer smartphones, such as the Google Tango compatible devices (Klingensmith et al. 2015). Therefore, such approaches can facilitate augmented reality environment rapid prototyping and authoring in a straightforward manner without requiring user expertise on computer science.

The Role of Presence in Cultural Heritage

"Presence" refers to the phenomenon of people behaving and feeling as if they "are there" in the virtual world created by computer displays (Ioannides et al. 2017). It is an incredibly powerful sensation, which is unique to MR, as it is not possible to recreate it in any other medium.

The Role of Illumination in MR Presence for Cultural Heritage

Introduction

There are two key components that are necessary in order to achieve the right illumination and thereby a high sense of presence in a MR cultural heritage environment: *authentic appearance of the light* and the *correct dynamic range*. Prior to the introduction of electricity, past societies relied entirely on daylight and lighting from flames for illumination. Any MR cultural heritage environment which is lit by modern lighting would thus not be authentic. In addition, the real world contains a wide range of lighting conditions, from dark shadows to bright sunshine. The MR environment needs to recreate this dynamic range of a scene. Where this is not possible using existing technology, techniques such as tone mapping need to be used.

High-Dynamic-Range (HDR) Environments

The dynamic range in a scene is defined as the ratio between the darkest part of the scene and the brightest. While the human visual system is able to adapt to the full range of light in a scene, traditional (also known as low-dynamic-range (LDR)) imaging is not able to capture or display a dynamic range of more than 256 to 1 (8 stops). High-dynamic-range (HDR) imaging, on the other hand, by using 32 bit IEEE floating point values to represent each color channel, can capture and display all the visual data in a scene. Failure to capture the full range of visual data can lead to important information being missed due to under- or overexposed regions in the image. Even if a scene has been captured, or created in HDR, detail can still be lost when the image is subsequently displayed on a device which is not HDR. In such a case, the HDR images need to be tone mapped in order to attempt to preserve the perception of the real scene on the LDR device. Many tone mapping operators (TMOs) have been presented over the years. More recently new TMOs have needed to be developed specifically for displaying 360° HDR images on head-mounted displays (HMDs) which are not yet HDR display devices. This is because the lighting in a full environment can vary significantly depending where the person is looking. HDR imaging is especially important in MR environments to ensure the virtual objects are relit with the same levels of lighting as in the real scene. As such, HDR is increasingly being been used within CH applications to improve their authenticity.

The Impact of Virtual Narrators to Presence in Virtual Museums

One of the important aspects which enhance the feeling of presence in CH (Papaefthymiou and Papagiannakis 2017) is the interaction with and behavior of the virtual narrators. These narrators should have humanlike behaviors, so that the visitors will feel like the virtual narrator that is

speaking to them is real and that he/she is in the same room with them. An issue that rises at this point is how a virtual narrator can be as realistic as possible, with humanlike behavior and characteristics. For a virtual character to look as real as possible, it is not enough just to create him/her programmatically with code. It would be more realistic if that character could be reconstructed out of a real human. That way, the appearance of the character would resemble the appearance of the real person based on whom this character was reconstructed. This can be realized by scanning a real person with the Occipital™ depth sensor, specially designed for this task. The photogrammetric method is one of the best methods yet to reconstruct the texture of a real person. By scanning the person with the special sensor mentioned before and applying the texture, a 3D model of that person can be created. That way, a 3D model of a real person will be able to be used in computer graphics and mixed reality applications, in order to tell a story and communicate with the people that will use the specific mixed reality application, as shown in Figs. 1 and 2 (Papaefthymiou and Papagiannakis 2017).

Mobile AR Interactive Applications for Virtual Museums

Mobile augmented reality systems (MARs) are increasingly currently being tested in rich content heritage environments by both creative professionals and laymen. Recent mobile hardware such as GPU-enhanced, multicore smartphones and novel untethered AR headsets (e.g., HoloLens by Microsoft) pave the way for a new breed of AR services and applications; however there are a number of issues to consider which regard the aspects of information presentation and physical interaction (Papaefthymiou and Papagiannakis 2017; Papagiannakis 2017; Ioannides et al. 2017; Kateros et al. 2015; Li and Duh 2013). With respect to direct hand interaction, there are limitations in handheld devices where the free hand is used for interaction with the 3D objects (e.g., small screen size, unsuitability of point and click gestures for manipulation, finger occlusion), whereas in HMDs hands are an intuitive input channel although bimanual interaction cannot ensure better performance than single-hand interaction, and it is important to optimally assign functions to two hands. For example, in recently

Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums, Fig. 1 The hologram of the priest of the Asinou Church and the viewer interacting via gestures through Microsoft HoloLens, in the ITN-DCH project (Papaefthymiou and Papagiannakis 2017)

Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums, Fig. 2 Digitization of the priest of Asinou Church (to reconstruct his 3D model as a virtual narrator) using the Structure Sensor (Papaefthymiou and Papagiannakis 2017)

introduced ARKit by Apple, which represents a commercial tipping point in terms of mass-market adoption of AR technology, interactions are kept simple with object's movements restricted on a plane, and the possibility of recognition of conflicting gestures. On the HMD side Microsoft HoloLens, although it has promised a hands-free experience, interaction can be frustrating given the limited field of view and the misreading of gestures. Although the promise of MARs is turning into reality, the technical challenges with respect to computational efficiency, information retrieval from different data sources, markerless detection, and hand gesture recognition performance still affect the overall user experience when interacting with MARs.

Immersive Experiences for Interaction with Cultural Heritage

Mixed Reality Installations

Mixed reality has the potential not only to increase motivation to learn but also to raise interest on CH. Thus, CH institutions can increase their appeal and enhance visitor engagement through interactive installations that include public displays (Partarakis et al. 2017). In addition to improving the aesthetic experience, mixed reality environments have influence on visitor experience, thus favoring the probability of revisiting a specific attraction (Jung et al. 2016). Apart from providing an enjoyable experience, mixed reality installations can facilitate cultural awareness, historical reconstruction, and heritage awareness. State-of-the-art approaches are not limited to installations in indoor spaces (Grammenos et al. 2012), but can also involve vehicles that act as portable kiosks (Zidianakis et al. 2016).

Setups and Interaction

Interactive installations in public spaces such as in CH institutions have certain requirements in terms of interaction and setup. The installations need to adapt to fit to the space available, provide content which interests both domain experts and non-expert users, and also present thorough information on demand (Mortara et al. 2014). At the same time, the system design should provide information immediately and support straightforward interaction techniques. Multiuser interaction with public displays is an open issue and constitutes an active area of research. Once people approach the interactive display, they decide their actions with regard to the system. Especially in the context of MR applications, the establishment of interaction with a public display involves transitioning from implicit to explicit interaction (Vogel and Balakrishnan 2004) as the users become engaged to the pervasive display.

Tangible interaction is a form of interaction with mixed reality installations in which physical items act as mediators between the users and the

environment. One aspect of tangible interaction refers to physical objects, which are simply the medium of communicating information. For instance, physical paper is employed as a portable display, augmenting maps or glass-protected models (Grammenos et al. 2011). Interactive maps (Margetis et al. 2017) are a mixed reality application, where printed maps are augmented with additional multimedia information. Furthermore, tangible interaction can involve objects which have meaningful substance with a semantic meaning, such as smart objects (i.e., physical items equipped with sensors such as RFID tags). Smart objects can facilitate related information in its context of use (Petrelli et al. 2016).

Bridging Worlds: Combining AR, MR, and VR

Digital cultural heritage content is combined with physical 3D replicas (Bugalia et al. 2016) in order to provide a virtual tour in architectural sites using MR. This approach has the advantage of moving in a wall-projected 3D virtual environment while placing a physical model in front of the users to act as a minimap assisting navigation. Head-mounted displays are employed in the context of CH foundations for holographic AR and additionally support VR visualizations (Pedersen et al. 2017). VR can act as a medium to visualize CH exhibits otherwise unavailable to users as well as reenactments of historical events offering hands-on experience regarding unattainable content. Such indicative examples of VR usage are elements which are under conservation or even stolen (The Museum of Stolen Art 2017) and such as the battle of Thermopylae (Christopoulos et al. 2011), respectively. A different approach for mixing realities involves using tangible objects as souvenirs which summarize narratives as they were presented to users (Petrelli et al. 2017), acting as personalized keepsakes of their visit in CH institutions. Finally, an interesting approach at Geevor Tin Mine Museum (Jung et al. 2017) combines AR, VR, and 3D printed objects with the common goal of adding value to the overall user experience. The technologies are employed for enriching visits (AR), providing access to inaccessible areas (VR), and souvenirs which the users can keep, respectively (3D printing).

The Role of Gamification in Cultural Heritage

Gamification has been applied to a number of application domains including CH, and it is a popular approach to increase the entertainment and thus the motivation factor of users (Vassileva 2012). It is different from computer games even if it shares a lot of common theories and practices of development. It is considered to be one of the more recent developments of computer game design principles that have been researched since their appearance (Liarokapis et al. 2017a). A major objective of gamification is the improvement of users' engagement that can provide positive effects, but the effects are heavily dependent on personalization (Hamari et al. 2014). Recently, an interactive tool called PhotoTrip was presented that can autonomously recommend CH locations along travel itineraries (Bujari et al. 2017). The application can identify these points of interest by gathering pictures and related information from social media and then provide suggestions and recommendations.

Gamification elements also exist in a number of simulations ranging from serious games to virtual and augmented reality. Similarly, edutainment and gamification are argued to be common recurring themes in the fields of education and cultural communication (Mancuso et al. 2017). In terms of virtual reality, gamification elements were recently shown in a kinesthetic application of sculpturing Cycladic figurines (Koutsabasis and Vosinakis 2017). The user takes the role of an ancient craftsman who creates a figurine with bare hand in a virtual reality environment. In another study, an immersive virtual underwater environment was developed to explore Mazotos shipwreck site and get relevant information about it and its contents (Liarokapis et al. 2017b).

In the following sections, key recent MR projects with rich gamification elements are presented.

Playful Interaction with Cultural Heritage Exhibits (Improved UX)

Immersion is based on covering physically a person's stimuli, namely, vision, spatialized sound,

and haptic feedback (Bowman and McMahan 2007). Haptic feedback (Ott et al. 2007) is examined in literature as an additional means of enhancing immersion. Kosmalla et al. (2017) combine tactile feedback from physical worlds with a virtual rock climbing environment in combination with full body movement and exertion. Immersion is also strongly related to the interaction process: in addition to perceiving a mixed reality (MR) application with human senses, the interaction modality employed constitutes a decisive factor in feeling of immersion and the overall user experience. Contrary to mission-critical domains such as a working environment, CH applications belong to a field in which users are more open to novel alternate interaction modalities. Requirements such as precision and efficiency are not fundamental in such a context, as users may be willing to sacrifice precision and overrule tiredness for entertainment and playful user experience (Drossis et al. 2013a). Playfulness encourages exploration, fosters creativity, and stimulates social interaction by entertaining users and allowing them to escape from the reality (Tsekleves and Darby 2017). Playful interaction is employed for attracting users toward public installations and therefore facilitating user engagement (Williamson and Sundén 2015).

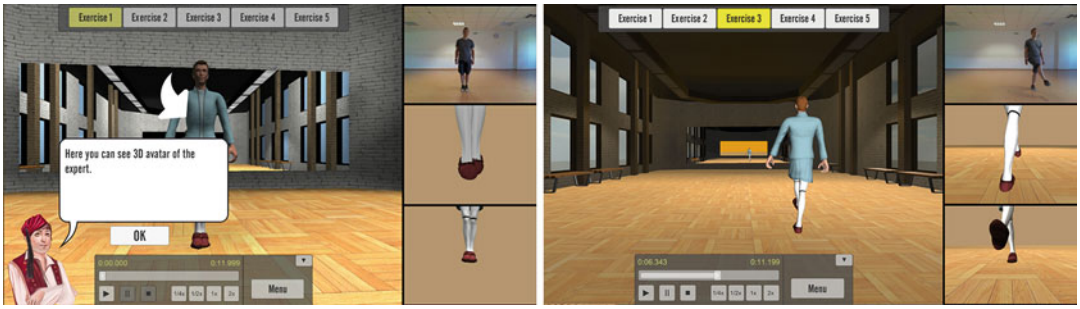
Re-Play: A Cultural Heritage Project that Allows to Replay Ancient Games

In Europe only, there are over 3000 Traditional Sports and Games (TSG). The EU project Re-Play has focused on two families of TSG (Gaelic and Basque) that are integral to the fabric of their communities of origin and have successfully staved off this trend of convergence. The group at MIRALab, University of Geneva, has focused on the development of a realistic real-time animation and rendering platform that enabled the visualization of the virtual national sports heroes as well as the visualization of avatars representing the local heroes (Tisserand et al. 2017). This state-of-the-art animation-rendering system includes dynamic muscle effects, which are modeled over the skin using a novel GPU approach. Based on existing MRI datasets and accurate reconstructed 3D models, the Re-Play platform computes the displacement map and assigns weights to each coordinate in the displacement map based on EMG measurements. To increase the feeling of immersion, photo-realistic 3D models acquired using a 3D scanner have been employed to animate and render the virtual sports heroes.

Gamification Applications for Folklore Dance

Intangible cultural heritage (ICH) includes fragile expressions mainly transmitted orally or by gestures from one generation to the next. In order to support the learning and transmission of ICH expressions, gamification can also be used. Based on the theory of "experiential learning" (Kolb, D.A., 1984, Experiential learning: Experience as the source of learning and development, Englewood.), one of the main pillars of game-based learning, the acquisition of learning is achieved by observing, reflecting, mentally representing, and enacting movements. In accordance with this theory, within the i-Treasures (Dimitropoulos et al. 2018) project, a number of game-like applications for sensorimotor learning of specific dance types and other activities involving full body gestures were designed and developed to support the learning and transmission of a number of ICH expressions. Specifically, a serious game application for transmitting ICH knowledge concerning the Greek traditional dance "Tsamiko" was developed (Kitsikidis et al. 2015) and shown in the figure below. The game was structured as a set of activities, aiming to teach different variations of the dance allowing users to learn by either observing experts' prerecorded movements in the Observe mode or by starting practicing the dance step sequences respectively in the Practice mode (Fig. 3).

During the Practice mode the learner is expected to imitate the moves of the expert avatar displayed on the screen. The addition of a virtual tutor to correct/manipulate/guide the user by providing visual and audio feedback was also supported in order to encourage the learners' "participation" and engagement.



Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums, Fig. 3 Observe and Practice screen of Tsamiko's gamified application within the i-Treasures EU project (Kitsikidis et al. 2015)

Survey of Recent MR Methods for Virtual Museums

In Table 1, a summary of key papers in the last 7 years, after the last relevant survey paper from Anderson et al. (2009), is presented. Although there is no specific MR method that features gamified storytelling with heightened interaction that still maintains full immersion and the feeling of presence, several conclusions and recommendations for next lines of research can be drawn and summarized.

The MR technologies that are used in the key papers (located in Table 1) contribute to the preservation of cultural heritage, each one with its own level of storytelling, presence, gamification, interaction, and tracking methods. Since all of the installations below are MR applications, many of them take into account the gamification field, in order for those applications to be interesting and fun for the viewers. Some of them include storytelling elements (e.g., Papaefthymiou and Papagiannakis 2017; Pedersen et al. 2017), which are used to inform the viewers about the story of a monument, for instance, thus contributing in cultural heritage curation. Furthermore, it can be noted that most of the MR methods below support partial immersion and few of them support full immersion. The term "immersion" is included in purpose as it can be easily quantified based on the display, whereas "presence" is elusive and depends on many parameters and thus difficult to provide that holds true throughout a simulation. VR HMDs thus support full immersion, whereas AR and holographic AR support partial one. Moreover, some applications that run tethered with a computer and do not support VR or AR provided no immersion at all. The majority of these key papers use mobile AR or holographic AR, and that explains the majority of the partial immersion entries on Table 1. A recommendation at this point would be that there should be more MR applications that support desktop or mobile VR with full immersion, as it creates a more realistic experience for the viewers because they do not have access to the real world and the feeling of presence is respectably higher than it is with partial immersion. These technologies can also be categorized in two additional categories, tethered and untethered, according to if an installation needs to be connected to a PC or not (standalone device), respectively. An example of an untethered MR technology, which can be found in the table below, is the Papaefthymiou and Papagiannakis (2017), which uses the Apple iPad Pro device in order to run. It uses Apple's ARKit for camera tracking. The viewers' movements are not limited by cables (since no cables are used), which enhances the feeling of presence as their movements would not be limited if they were exploring the real monument. Also, gamification and storytelling elements are supported, and along with the feeling of presence and freedom of movements, all those elements create the perfect experience for the viewers. Another version of this work runs on the Microsoft HoloLens holographic AR HMD, which is also an example of untethered AR.

On the other hand, there are some great MR applications (e.g., Pedersen et al. 2017; Drossis

Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums, Table 1 Comparison of recent MR methods for virtual museums

Mixed reality method	MR installation	Gamification	Storytelling	Interaction	Tracking	Immersion	Intangible heritage
Anderson et al. (2009)	Rome Reborn serious game	x	x			–	No
	Ancient Pompeii application	x	x			–	No
	Parthenon Project	x	x			–	No
	Virtual Egyptian Temple	x	x	Walking/ movement	Cave Automatic Virtual Environment (CAVE)	Full	No
	The Ancient Olympic Games	x	x	Navigation wand of the VR system		–	No
	Virtual Priory Undercroft	x	x			–	No
	Commercial historical games	x	x			–	No
Bugalia et al. (2016)	3D printed models, projector, camera, laser pointer	x	x	Laser pointer	IR camera, project camera, view camera	Partial	No
Dong et al. (2017)	VR application using Focus 3DX 330 Faro scanner, Spheron PanoCam, two GoPro Hero 4 cameras for scanning, and utility for rendering	x		Depending on VR platform	Depending on VR platform	Full	No
Drossis et al. (2015)	3D model prototype (depth sensor, touch screen, interactive cube, projection)	x		Touch screen, interactive cube, walking/movement	RGB-D sensor, Kinect or Asus Xtion camera	Partial	No
Gimeno et al. (2011)	Region of Valencia map, seven pointers, and Hostess	x		Walking/ movement	Map, pointers, Kinect camera	Partial	No
Grammenos et al. (2011)	Tabletop augmented reality system		x	Finger-based input	Projector and pieces of white paper	Partial	Yes/no
Javornik et al. (2017)	Apple iPad Pro	x		Touch screen	Inner iPad camera	Partial	Yes
Kitsikidis et al. (2015)	Microsoft Kinect Sensor	x		Motion capture	Skeleton tracking with Kinect Sensor	Partial	Yes
Kosmalla et al. (2017)	HTC Vive with Leap Motion	x		Controllers	Positional and hand tracking	Full	No

Koutsabasis and Vosinakis 2017	Leap Motion	x		Hand gestures	Hand and finger tracking	Partial	No
Liarokapis et al. (2017b)	HTC Vive	x		Controllers	Motion and laser based	Full	No
Margetis et al. (2017)	Interactive map tabletop system		x	Handwriting, gestures, touch/ click	Projector, high-resolution camera, depth sensor	Partial	Yes/no
Nakevska et al. (2017)	CAVE	x	x	Back projection on walls	Pressure sensors	Full	Yes/no
Papaefthymiou and Papagiannakis 2017	Oculus Rift	x	x	Controllers	Rotational and positional (sensors)	Full	No
Papaefthymiou and Papagiannakis 2017	Apple iPad Pro	x	x	Touch screen	Apple's ARKit for camera tracking	Partial	No
Papaefthymiou and Papagiannakis 2017	Microsoft HoloLens	x	x	Voice commands, gestures	Body motion	Partial	No
Papagiannakis et al. (2004)	DELL P4 M50 Mobile Workstation	x			Real-time markerless camera tracking	Full	No
Pedersen et al. (2017)	Meta developer Kit	x	x	Gestures	Markerless surface tracking, head movement	Partial	No
SpatialStories (2018)	Toolkit for VR/AR platform	x	x	Depending on VR/AR platform	Depending on VR/AR platform	Full/partial depending on the platform	No
Tisserand et al. (2017)	Computer with Kinect Sensor for traditional sports preservation	x		Movement	Kinect Sensor	Partial	Yes

et al. 2015; Tisserand et al. 2017), which support gamification and/or storytelling elements, but they limit the movements of the viewers due to the existence of cables or need of a connection with a desktop PC. Although these applications are impressive and greatly contribute to cultural heritage preservation, they restrict the freedom of movement to the users, which in some cases may disrupt the feeling of presence. Based on this discussion, it is recommended for MR applications to be able to run in MR installations that do not restrain the movements of the viewers in any way. Without restriction of movements and with full immersion, the experience of a viewer will reach very high levels. Finally, SpatialStories (Foni et al. 2010), a very recent commercial effort, is a toolset for real-time interactive VR/AR experiences featuring storytelling for non-programmers. Although it has not yet been fully tested, from information gathered from their website, its manual, and its videos, it poses a promising commercial solution in contributing to MR cultural heritage applications.

Conclusions

In conclusion, the ability to innovate in the field of MR gamified storytelling while maintaining presence in the virtual museums of the future will be directly related to the ability to find synergies between the above fields of knowledge, without forgetting that new technologies can play a transcendental role in this equation. And as the quintessential reductive machine, MR technologies are employed as the device that will restore its unity through multiplicity and fragmentation. Hence this work needs to be considered as a further step toward reconciliation and a renewed mutual beneficial relationship between humanities, social sciences, and computer science.

Cross-References

► Gamification and Serious Games
► Gamification in Crowdsourcing Applications

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MMO

▶ World of Tanks, MMO Strategy Freemium Game

MMORPG

▶ Detecting and Preventing Online Game Bots in MMORPGs
▶ Disney Toontown Online, a Massively Multiplayer Online Role-Playing Game
▶ Fantasy XVI Online, a Massively Multiplayer Online Role-Playing Game
▶ World of Warcraft, a MMORPG with Expansions

Mobile Applications

▶ Indigenous Language Revitalization with Stories and Games

Mobile Applications for Behavior Change

▶ Mobile Persuasive Applications

Mobile Augmented Reality

▶ Conceptual Model of Mobile Augmented Reality for Cultural Heritage

Mobile Augmented Reality for Cultural Heritage

▶ Conceptual Model of Mobile Augmented Reality for Cultural Heritage

Mobile Cloud Gaming

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Synonyms

MCG

Definitions

Mobile cloud gaming (MCG) is a new type of mobile gaming, in which games are stored, synchronized, and rendered in the remote cloud platform and delivered to mobile users using video streaming technology.

Introduction

As a killer application in the mobile app market, the growth of mobile gaming is very impressive in the past decade. The major obstacle that may hinder the further growth of mobile gaming is the constraint of limited resources on mobile devices. However, it is fortunate that recent advances in cloud computing shed lights on the feasibility of playing high-end video games on mobile devices.

Mobile cloud gaming (MCG) enables mobile users to play games in the cloud and thus mitigates the tension between high requirements of video games and limited resources on mobile devices. By offloading computation-intensive tasks to the powerful cloud platform, the capacity of mobile

devices can be significantly augmented (Wei Cai et al. 2013; Zhang et al. 2013; Wen et al. 2014).

Unlike traditional mobile gaming, mobile cloud gaming offers many novel features: *Firstly*, with mobile cloud gaming, there is no need for mobile users to constantly upgrade their mobile devices; *secondly*, mobile users are allowed to start game playing instantly, without downloading and installing mobile game apps; *thirdly*, mobile games can be platform-independent under the mode of mobile cloud gaming. There is no need for game developers to build a separate game app for each mobile platform (e.g., iOS, Android).

Technical Challenges and Problems

Compared to common cloud gaming, the features of mobile devices pose some additional challenges for mobile cloud gaming. The main challenges of delivering MCG services to mobile devices include the following aspects:

1. *Heterogeneity of Mobile Devices*: There exists significant diversity among hardware configurations of mobile devices (including screen size, resolution, bandwidth, and CPU/GPU). The MCG service provider should consider the heterogeneity of mobile devices when delivering video game streams to mobile devices.
2. *Diversity of Mobile Games*: Different game genres have different QoE (Quality of Experience) requirements. For example, a slight increase of interaction delay is intolerable for the first-person shooter (FPS) games, while it may not be observable for the war strategy games. Therefore, the decision on MCG resource provisioning should consider the difference on QoE requirements among different game genres.
3. *Unreliable Wireless Transmission*: The mobile devices are connected with the MCG platform via wireless channels. However, the conditions of wireless channels are intrinsically unreliable and vary with time. It makes the transmission of video game streams easy to violate the strict latency requirements. Due to the stochastic nature of wireless channels, it is necessary to ensure that game video streaming can adapt to the changes of wireless network conditions.
4. *Limited Battery Life*: In addition to providing sufficiently short latency for real-time gaming and reacting to user inputs timely, it is necessary to take energy efficiency of mobile devices into account. It is critical to reduce energy consumption of computation, communication, and display for mobile cloud gaming.

The above challenges raise a number of questions that should be addressed. Among them, the first critical question is how to better evaluate the QoE of mobile gamers. Only when the QoE target is clear can the MCG service provider know how to provision and configure its cloud resources in a reasonable way. The QoE of game players in MCG systems can be generally modeled by a set of objective and subjective factors. Wang and Dey (2009) characterized user QoE by video settings, network factors, image quality, etc. *Game Mean Opinion Score (GMOS)* (Schaefer et al. 2002) has been widely used to map these factors to the value of QoE. However, these QoE models often assume that players are in the same physical context when playing games. When using mobile devices to play games, the physical context can be highly dynamic since the mobility of users will incur certain changes of their surrounding environment (e.g., where the player is, what the player is doing, and so on) (Benford et al. 2005). Mobile devices provide an opportunity to sense the physical context by analyzing information from multiple sensors such as motion sensors, light sensors, and acoustic sensors. It is important to integrate the availability of context sensing when designing a more realistic QoE model of mobile cloud gaming.

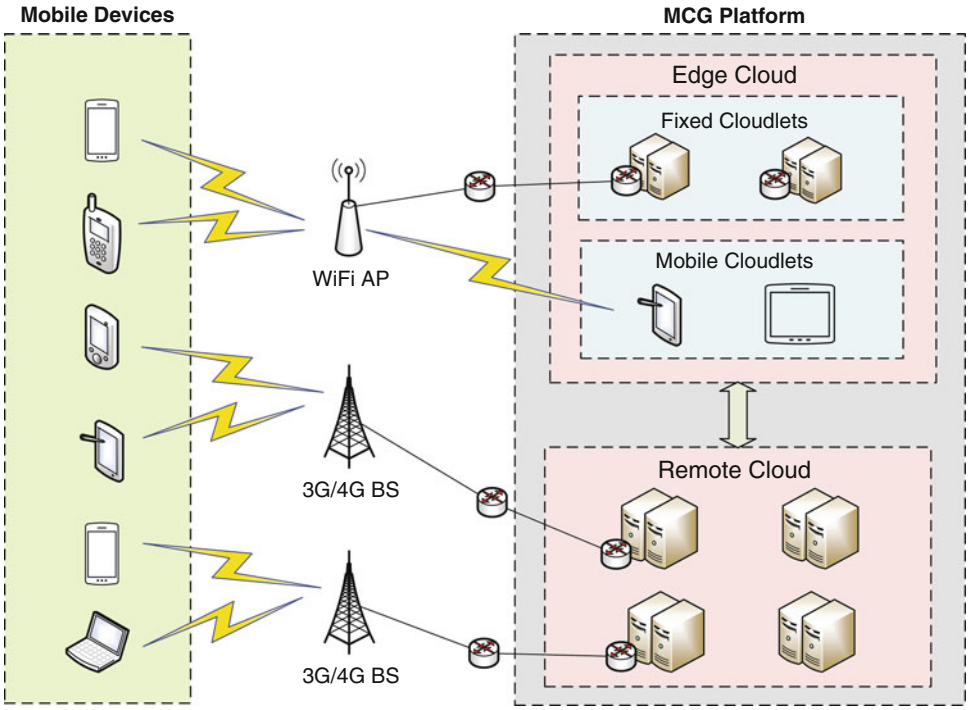
The provisioning of MCG resources also should be able to maximize the QoE of gamers (including latency, video quality, etc.). In the meanwhile, due to the cost of delivering high QoE, the MCG service provider also needs to take service cost into account during optimization. To achieve the tradeoff between the monetary cost incurred by provisioning cloud resources (e.g., CPU, GPU, bandwidth) and service quality (e.g., delay, frame rate, resolution) experienced by

mobile game players (Gao et al. 2016; Hu et al. 2016), the MCG service provider should dynamically adjust the amount of provisioned cloud resources according to the variations of user demand. Chuah et al. (2014) provided a comprehensive survey on how to efficiently leverage hardware resources to satisfy the demand of graphics rendering and video coding in cloud gaming. It is of more interests to analyze the complexities of scheduling cloud resources from a broader perspective. As the difference among game genres affects the demand pattern of cloud resources, the resource efficiency can be improved by optimizing resource allocation among different game genres jointly. However, as indicated by Chen et al. (2014), it requires further effects to solve the problem of consolidating multiple MCG tasks (e.g., rendering, video coding and transmission) on cloud servers.

Streaming gaming video in such a stringent time-constrained scenario is also a major challenge in MCG. One solution to cope with this problem is data compression. After game scenes are computed on cloud gaming servers, they have to be compressed before being streamed. This can be done in one of the three data compression schemes: (i) video compression, which encodes 2D rendered videos, (ii) graphics compress, which encodes 3D structures and 2D textures, and (iii) hybrid compression, which combines both video and graphics compress.

Architecture and Design of MCG Systems

It is challenging to architect a cost-effective MCG platform that can provide users with high QoE. As a delay-sensitive service, game players are sensitive to interaction delay during game playing. The MCG platform should be able to adjust resource allocation for mobile users dynamically in order to meet the delay constraint. According to the distance to mobile devices, the authors briefly classify existing MCG architectures into two categories, namely, *Remote Cloud* and *Edge Cloud* (as shown in Fig. 1).



Mobile Cloud Gaming, Fig. 1 Architectures of mobile cloud gaming systems

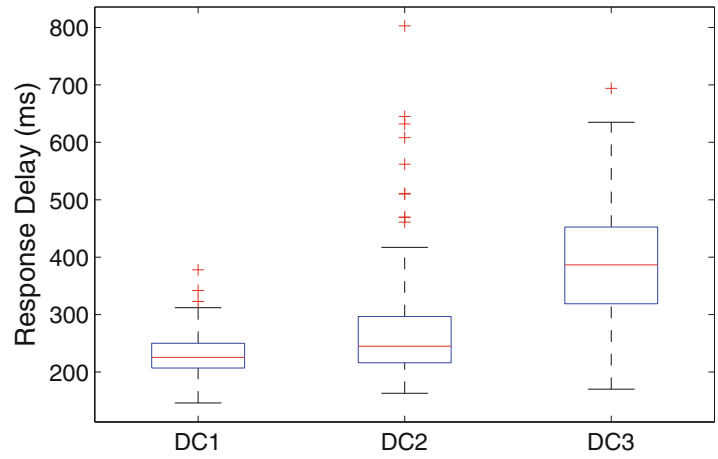
Remote Cloud refers to the architecture in which a MCG service provider relies on a remote cloud platform to deliver the mobile cloud gaming service to mobile users. The architecture of Remote Cloud has been widely adopted by leading MCG service providers, such as Ubitus and G-Cluster. Physically, the remote cloud can be provisioned on a set of geographically distributed data centers in order to serve mobile users in different regions.

As the MCG service provider can directly rent cloud resources (e.g., VM, bandwidth, storage) from the third-party cloud service providers (e.g., Amazon, Microsoft), the construction and maintenance of the remote cloud infrastructure can benefit significantly from mature services of cloud service providers. Remote cloud could be very reliable and powerful. It is also easy to expand the scale of provisioned resources according to dynamic user demands.

The major issue with the mode of the remote cloud is network latency, as most large cloud service providers only deploy their data centers at a limited number of locations. For players who are far away from any cloud data center, network latency will deteriorate their gaming experience significantly. Figure 2 shows the response delay when selecting different data centers when using the remote cloud. The requirements on high video quality and high frame rate will further exacerbate the latency problem. To achieve real-time transmission of game video streams under the mode of the remote cloud, researchers have performed quite a few research studies on video codec optimization, network transmission, and QoE adaptation jointly. As stated in Jarschel et al. (2011), the QoE of cloud gaming is highly related to downstream packet loss and downstream delay, which indicates the necessity of connecting the nearest and fastest server.

Edge Cloud is another attractive architecture proposed to address the latency problem of remote cloud, in which cloudlets (Satyanarayanan et al. 2009) close to the mobile device are responsible for task offloading in order to meet the strict latency requirement. Generally, a *cloudlet* is a kind of resource-rich computing entity with a broadband network connection in the proximity of mobile devices. There are two kinds of cloudlets: *fixed cloudlets* (e.g., desktop PC, gateway, and set-top-box) and *mobile cloudlets* (e.g., tablets, pads). As a mobile device is well connected with nearby cloudlets, the intensive computation tasks (e.g., frame rendering, video encoding) can be completely migrated to the nearby cloudlets.

In spite that edge cloud is a promising approach, several intrinsic problems should be addressed before its successful deployment in reality. First, the MCG service provided by cloudlets is not reliable and depends on the existence of cloudlets in the proximity. The problem is even worsened for the case of mobile cloudlets. Second, the decentralized nature of cloudlets makes it hard to be operated and managed. For an edge



Mobile Cloud Gaming, Fig. 2 Response delay when selecting different data centers in remote cloud

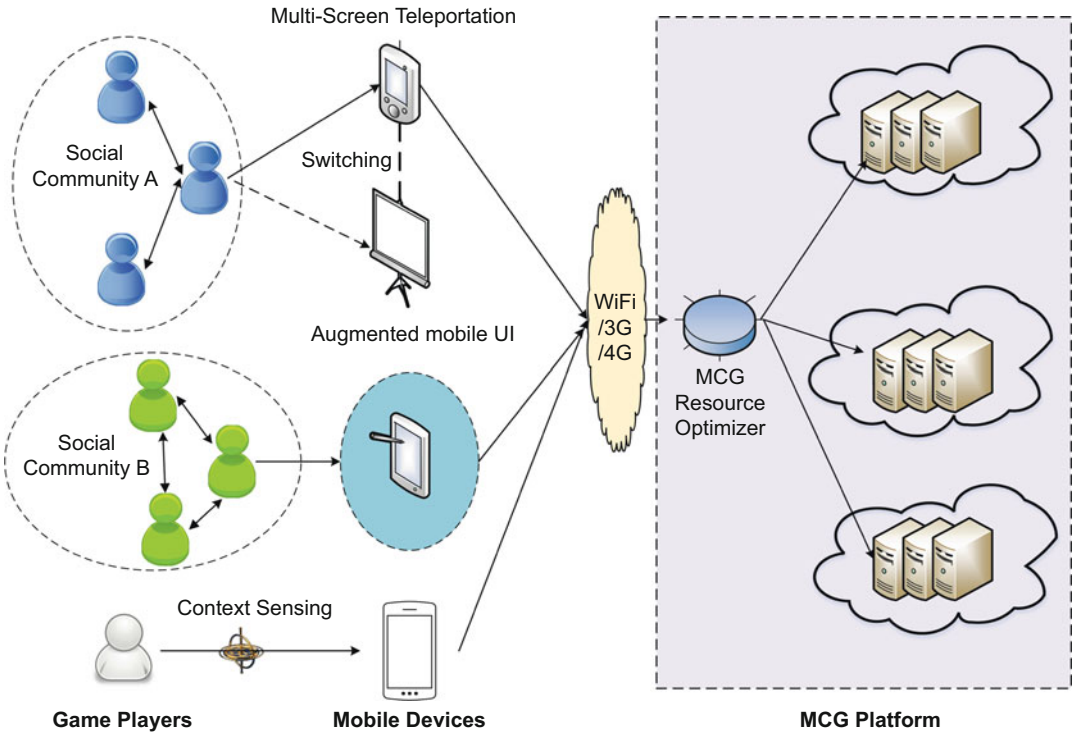
cloud with many volunteer cloudlets, the cost of cloudlet management and maintenance will be nontrivial for a MCG service provider. Third, effective incentive mechanisms should be adopted to encourage individuals to deploy more cloudlets. To provide MCG services, a cloudlet should contribute its own resources (including CPU cycles, battery energy, and disk space). Without monetary incentives, it is difficult if not impossible to stimulate resource sharing between cloudlets and mobile devices. In addition, the issues of security and privacy caused by task offloading should also be considered.

In the spectrum of architectural design of MCG platforms, *Remote Cloud* can be regarded as one end and *Edge Cloud* could be the other end. Either of them has its own pros and cons as the authors have explained in the above. The authors believe that, *Hybrid Cloud*, which is a combination of edge cloud and remote cloud, is a better architecture to support mobile cloud gaming. It can seamlessly integrate both proximate and remote cloud resources to deliver a smooth gaming experience for mobile game players.

However, the architecture of hybrid cloud will also complicate the system design. In the real scenario, task partitioning among mobile devices, cloudlets, and remote cloud servers will become very sophisticated. The decision on task partitioning needs to take the constraints on response delay, resource availability, energy consumption, and bandwidth conditions into account. In the current stage, the research on hybrid cloud is still in its infancy.

Potential Directions and Opportunities

In this section, the authors discuss a few directions and opportunities for future research on mobile cloud gaming. Figure 3 provides an illustrative example on the directions covered here, which will be explained one by one in the following parts.



Mobile Cloud Gaming, Fig. 3 An illustrative example on potential opportunities on mobile cloud gaming

Augmented User Interface for Mobile Devices

User interface plays an important role for user QoE of mobile cloud gaming. Particularly, many mobile devices (e.g., smartphones, pads) cannot support the traditional physical keyboard and mouse as the input, and only touch screen is available as the gaming control. Therefore, it is critical to augment the current user interface of mobile devices to better support mobile cloud gaming. The tracking of a mobile device can be realized by analyzing received signals such as RF signals and acoustic signals. By combining the arrival sequences of measured signal angles from two or more receivers (e.g., antennas, speakers), the movement of a mobile device can be precisely sensed (Vasisht et al. 2014; Agrawal et al. 2011). The augmented interaction techniques will significantly enhance gaming experiences on mobile devices.

Environment-Aware Mobile Game Playing

Different from fixed game consoles (e.g., desktop PCs, gaming boxes), mobile cloud gaming enables gamers to play games anywhere at anytime. Such high mobility implies that the surrounding environment of a gamer may keep changing during game playing. With a rich set of sensors (e.g., microphone, light sensor, camera, GPS, accelerometer) available on today's mobile devices, it is possible for mobile devices to sense the physical context of their surrounding environment (e.g., indoor or outdoor, fixed or moving, light or dark). Moreover, the emergence of wearable devices (e.g., smartwatches, smartglasses) shows a bright future to sense fine-grained physical context. By adaptively generating game contents according to the changing physical context, mobile game players can enjoy enriched gaming experiences. As an example, the MCG platform can adapt the quality, frame-rate, and contents of game video streams according to the light condition and moving speed of a mobile user. Such environment-aware adaptation can improve the user QoE significantly.

Integration of Social Networks with MCG

By integrating social links among gamers with the MCG system, mobile cloud gaming can provide a user-centric gaming environment, which dramatically transforms the traditional gaming experiences. Social mobile cloud gaming creates a virtual living-room experience, by allowing remote mobile gamers to play games together, watch game playing of other friends, and communicate via various communication modalities (such as text, graphics, audio, video, and so on). For example, twitch-like live video game broadcasting (Hamilton et al. 2014) has already attracted significant attention from game players. A gaming broadcaster often belongs to the same social community with his viewers. As the exchange of information flows between mobile players is supported by the MCG platform, the abundant resources in the cloud can better support the increasing number of mobile players. The MCG system can be highly scalable with the support of cloud infrastructure.

Multiscreen Teleportation of MCG Sessions

Nowadays, mobile gamers normally interact with multiple screens in their daily living environment (Hu et al. 2014). The sizes of these screens range from large (e.g., TV screen) to small (e.g., smartphone screen). To enjoy a better gaming experience, gamers are willing to teleport ongoing gaming sessions from a small screen to a large screen if without any interruption, and vice versa. Imagine that a user is playing a game on his smartphone when taking the subway back to home. Upon arriving at home, he can teleport his gaming session to the TV screen and play the game with a joystick. After leaving his apartment for dinner, he can switch the gaming session back to his smartphone. Such seamless teleportation among multiple screens will surely enhance the gaming experience of players. With the MCG platform, gaming session migration can be easily supported by the back-end cloud infrastructure.

As a promising solution to enable high-end video games to be played on resource-constrained mobile devices, the authors believe that mobile cloud gaming will definitely have a bright future in the coming era.

Cross-References

▶ Cloud for Gaming

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Mobile Devices

▶ Exploring Innovative Technology: 2D Image Based Animation with the iPad

Mobile Game

▶ Gardenscapes and Homescapes, Casual Mobile Games

Mobile Interface

▶ Tracking Techniques in Augmented Reality for Handheld Interfaces

Mobile Persuasive Applications

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Synonyms

Mobile applications for behavior change; Mobile-based behavior change support systems

Definition

Mobile persuasive applications are native or mobile web applications with inbuilt persuasive features that influence the attitudes or behaviors of users.

Introduction

B. J. Fogg has introduced the concept of "persuasive technology" to frame the domain of research, design, and applications of persuasive computers Fogg 2002). Persuasive technology refers to applications and interactive media which implement psychological principles of persuasion (like credibility, trust, reciprocity, and authority) aiming at positively altering users' disposition and behavior toward a predetermined goal.

It is now widely recognized that apart from relying on humans to influence others (e.g., life coaches, nutritionists, etc.), the conscious design of persuasive computer applications as a means for influencing human behaviors can bring about positive changes in many domains, including health, personal lifestyle and well-being, safety, and environment. This underscores the importance of persuasive technology, that is, its capacity to effectively influence the attitudes or behaviors of users so as to ultimately serve the personal and/or the social good (e.g., adoption of healthy diet habits, promotion of sustainable lifestyles toward green travels, or household waste reduction). Recent advances in computing, particularly mobile computing, leverage untapped opportunities to impact users' behavior for the better. In fact, field studies have provided evidence that smartphone applications achieve higher adherence to behavior change tasks (e.g., change exercise and nutrition habits to treat obesity) compared to their web counterparts or other paper-based programs with respect to retention, engagement, and effectiveness (Carter et al. 2013).

The key objective of the article is to explore the area of mobile persuasive applications, through presenting the most typical behavioral change goals they pursue, reviewing representative popular applications, and discussing the elementary principles considered in the design of mobile persuasive systems.

Attitude and Behavioral Traits Addressed by Mobile Persuasive Applications

Mobile devices represent a useful instrument for persuasive applications as they exhibit several desired characteristics and satisfying features (e.g., the requirement to assess and motivate the physical activity of a person may be satisfied by persuasive applications which take advantage of the readings of smartphones' built-in sensors) (Kasapakis and Gavalas 2015). The diffusion of mobile devices allows to reach a much wider audience while apps are easy to disseminate through the established mobile application markets; mobile devices come with an array of inbuilt sensors and may easily couple with wearable devices (such as smart wristbands, smartwatches, etc.) to accurately estimate a variety of user activities, for instance, the type, pace, duration, and location of physical activity (e.g., number of steps taken and/or stairs climbed), which may then be translated to meaningful statistical indicators (e.g., calorie consumption).

Recently, persuasion principles have been applied to the design of mobile applications which aimed at such diverse behavioral change goals (Gardeli et al. 2017; Langrial et al. 2013, 2017):

- Stimulation of enhanced physical activity: "fitness" apps supporting walking, running, hiking, and cycling workout
- Improvement of well-being and adoption of healthy lifestyles: monitoring of physical exercise, nutrition intake, smoke cessation, alcohol intake reduction, weight management, etc.

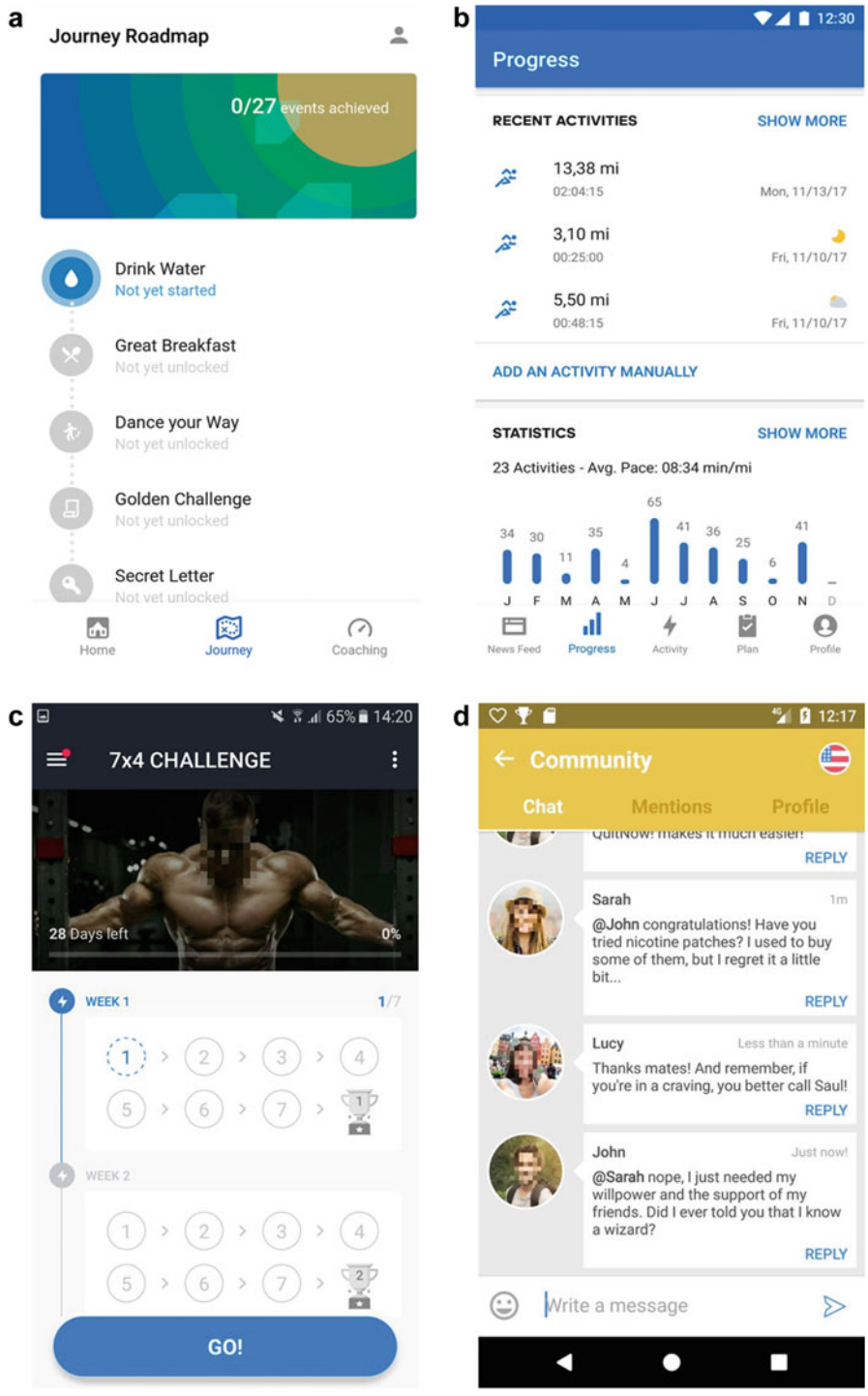
- Addressing health problems (e.g., obesity, heart disease, type 2 diabetes) and adherence to prescribed medication intake
- Mood monitoring, stress, and anger management
- Adoption of low-carbon lifestyle, e.g., encouragement to embrace environmentally friendly transport practices
- Preservation of shared physical resources and environmental awareness
- Improvement of driving behavior and safety

The number of mobile persuasive applications, serving the abovementioned behavioral change goals, has proliferated in the recent years. These applications employ several behavior change techniques (Conroy et al. 2014) to enhance awareness, increase motivation, and engage users with the task/activity at hand (a theoretical discussion of the key design considerations for such applications is provided in the next Section). For instance: the *Fabulous – Self-Care* app (https://play.google.com/store/apps/details?id=co.thefabulous.app) supports users in goal setting through monitoring tasks completion toward adopting healthy habits (see Fig. 1a); the *Runtastic Running* guides (https://play.google.com/store/apps/details?id=com.runtastic.and roid) users throughout running/jogging sessions via a voice coach while also providing detailed feedback on their performance (see Fig. 1b); the *Home Workout* app (https://play.google.com/store/apps/details?id=homeworkout.homeworkouts.noequipment) rewards users with badges when successfully completing a weekly program of exercises (see Fig. 1c); the *QuitNow! Quit Smoking* app (https://play.google.com/store/apps/details?id=com.EAGINsoftware.dejaloYa) allows social interaction and progress comparison among its users to further motivate them in quitting smoking (see Fig. 1d). It is noted that the illustrated apps are not chosen as the best manifestations of the persuasive technology but, instead, as representative examples of mobile persuasive applications on the basis of their popularity (>1M downloads).

Persuasion Design for Mobile Applications

Principles of social psychology, context-aware decision-making, as well as engagement strategies are commonly utilized as means of persuasive design throughout the design process of products and tools intended to influence positive behavioral changes. Oinas-Kukkonen and Harjumaa (2009) summarized their empirical findings to several postulates that should be taken into account when designing or evaluating persuasive systems. Firstly, persuasive systems should decompose persuasion to a multilevel process, as users are more likely to be persuaded when performing a series of incremental tasks. Designers should also take into account that technology is not neutral as it critically affects user behavior; hence, this should be communicated to users in order not to lower the level of persuasion. Furthermore, users are more likely to be persuaded when making commitments, and therefore persuasive systems should facilitate users in completing those commitments by organizing user tasks accordingly and offering consistency. Moreover, it is important that persuasive systems should support both a direct route to persuasion that focuses on the quality and punctuality of the information and also an indirect route that uses peripheral cues to associate positivity with the message without requiring much effort or information processing. Finally, persuasive systems should be useful to users and rather usable while also being discreet so as not to interrupt users when performing primary tasks.

So far, the Persuasive Systems Design (PSD) model has been the most generic conceptual framework in assistance of persuasive systems designers (Oinas-Kukkonen and Harjumaa 2009). The PSD model underlines the significance of persuasion context by addressing the intent (intended change), the event (use, users, and the context), and the strategy (persuasive message and delivery route). Moreover, it identifies four basic design principles to be incorporated in persuasive applications, some of which have been adopted from Fogg (2002):



Mobile Persuasive Applications, Fig. 1 (**a**) *Fabulous – Self-Care* app, health goal setting (image courtesy of TheFabulous); (**b**) *Runtastic Running*, self-monitoring of running performance (image courtesy of runtastic GmbH); (**c**) *Home Workout* app badge rewards (image courtesy of Leap Fitness Group); (**d**) *QuitNow! Quit Smoking*, social interaction with other users performing alike tasks. (Image courtesy of Fewlaps)

Mobile Persuasive Applications, Table 1 Methods employed by popular persuasive applications for addressing the persuasive design principles of the PSD model

Title	Fabulous – Self-Care	Runtastic Running	Home Workout	QuitNow! Quit smoking
Scope	Supporting users in adopting healthy habits	Motivating users to exercise (running/jogging)	Persuading users to exercise (gymnastics)	Supporting users to quit smoking
Primary task support	Collection of user data (e.g., sleep and training habits); illustration of detailed progress charts based on user goals	Collection of user data (e.g., age, weight, height); provision of custom training plans according to user goals (e.g., weight loss plan); illustration of detailed progress charts	Collection of user data (e.g., age, weight, height); provision of training plans according to user goals (e.g., full body exercise plan); illustration of detailed progress charts	Collection of user data (e.g., number of cigarettes smoked per day); illustration of detailed progress charts
Dialogue support	Task reminders via notifications/alarms; voice coach messages	Voice coach guidance throughout training sessions; leaderboard support; task reminders via notifications/alarms	Voice coach guidance throughout training sessions; badge/achievements rewards; task reminders via notifications/alarms	Badge/achievements rewards; task reminders via notifications/alarms; provision of an automated chat bot which supports users with scientific facts relevant to quitting smoking
Credibility support	Provision of verified scientific data via personalized messages about the importance of each healthy habit	Usage of GPS for accurate running/jogging distance measurement; integration with wearable fitness trackers to further increase the accuracy of measurements	The application can be linked and transfer data to *Google Fit* (https://www.google.com/fit/), the official fitness tracker app of Google	Provision of an automated chat bot which supports users with scientific facts relevant to quitting smoking; provision of a FAQ section with verified methods for quitting smoking
Social support	Users can share and compare their progress with friends through a dedicated service and popular social media platforms	Users can share and compare their progress with friends through a dedicated service and popular social media platforms	–	Users can share and compare their progress with friends through a dedicated service and popular social media platforms

- *Primary task support*, which involves support of the user to carry out her primary task through reduction (decomposition of complex behaviors into simple tasks), guidance along the attitude change process, and provision of information tailored to users' potential needs or interests, allowing users to self-monitor their own performance.
- *Dialogue support*, namely, enabling users to receive feedback while moving toward their target behavior through offering praise (via words, images, symbols, or sounds based on user behaviors), providing virtual rewards (as a credit for performing the target behavior), and reminding users of their tasks.
- *Credibility support*, which relates with designing systems so that they are more credible through inculcating trustworthiness (providing information that is truthful, fair, and unbiased), offering content incorporating expertise (i.e., knowledge, experience, and competence), highlighting the real people or

a
Story Missions
Save humanity and discover the source of the zombie plague!
Training Plans
Enrol to get fitter and faster, and put a shape to your missions
Airdrop
Recover a supply drop by running to a point in the real world!
Supply
Collect extra supplies for Abel Township on these unlimited length runs!
Interval Training
Customise your workout with sprints, runs, and walks
Race
Six races of 5k, 10k, and 20k length. Discover the hidden story at the end of Season 1!
Radio Abel
Listen to your favourite radio station hosts,
b
Home
Stats
Codex
Races
Social
Sun 30 Aug 10:50AM
Believe
3.82
1:04:51
17:06
Split Times
A Warning?
You're chasing up every report you received about zombie repellants, and today you're heading to a sawmill to question a suspicious group of people there.

Mobile Persuasive Applications, Fig. 2 (**a**) Zombies, Run! story missions and training plans; (**b**) Zombies, Run! progress charts and mission details shared in ZombieLink

organizations behind the system's content or services, and providing means to verify the accuracy of content.

- *Social support* which relates with fostering user motivation through social learning (observing other users who perform similar target behaviors), social comparison (comparing performance with the performance of other users), and normative influence (means for gathering together people who aim at the same goal).

Table 1 provides an overview on the methods employed by the example applications illustrated in Fig. 1 to address the basic design principles of the PSD model

Further to the persuasive design principles of the PSD, *gamification* (i.e., the use of game design elements in non-gaming contexts) is increasingly used as a design strategy in the development of persuasive systems (Cugelman 2013; Gardeli et al. 2017). The design of gamified applications entails the incorporation of appropriate motivational and playful elements in the core of interactive systems in order to attract and retain users' interest while achieving their goals (Papagiannakis 2018). Thus, the gamification approach is particularly relevant to the design of mobile persuasive applications. One of the most successful examples of gamification for persuasive systems is Zombies, Run! (https://play.google.com/store/apps/details?id=com.sixtostart.zombiesrunclient). In effect, users are immersed in running game sessions, being provided voice guidance to achieve exercise goals while also trying to survive the "zombie apocalypse." Also, users can share and compare their progress with other users via the complementary community website ZombieLink (https://zombiesrungame.com/zombielink/home/, see Fig. 2).

Conclusions and Research Prospects

Sufficient evidence already exists that smartphone applications may effectively support people in pursuing behavior change goals. Nevertheless, despite the recent conceptualization of generic methodologies and guidelines for designing persuasive systems (Oinas-Kukkonen and Harjumaa 2009), the selection and combination of design elements and technologies that effectively support behavioral change represent an open research issue. There is a growing need for field studies (involving real users for relative prolonged time periods) in a variety of usage situations and persuasion contexts that will allow

deeper understanding of the persuasion context and will eventually provide rich feedback on various design choices with respect to the target group and the desired outcomes (Langrial et al. 2017).

Although the PSD model represents a solid framework that suggests must-have design elements of persuasive applications, the formulation of design strategies that specifically suit the unique characteristics of mobile applications is still in need. For instance, the effect of contextual factors easily captured by mobile devices (e.g., location, activity, environmental and social context, etc.) could be considered in a revised PSD model. Potential revisions of PSD should also include the incorporation of selected gamification principles.

Cross-References

- ▶ Games and the Magic Circle
- ▶ Gamification
- ▶ Gamification of Modern Society: Digital Media's Influence on Current Social Practices
- ▶ Pervasive Games
- ▶ Transformational Games

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Mobile-Based Behavior Change Support Systems

▶ Mobile Persuasive Applications

Mocap

▶ Sketch-Based Posing for 3D Animation

Mod

▶ Counter-Strike Global Offensive, an Analysis

Modding

▶ Underground Design of Kaizo Games

Modeling and Mesh Processing for Games

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Synonyms

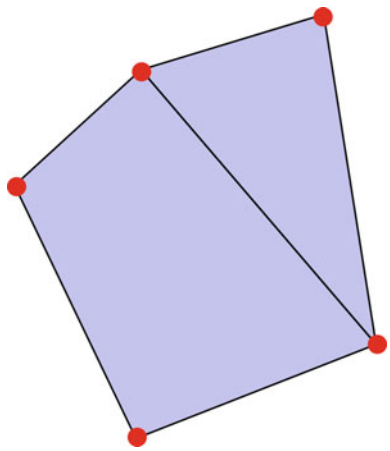
Digital geometry processing; Polygonal modeling

Definition

Mesh modeling is the process of constructing a polygonal mesh from scratch by basic operations or editing an existing mesh for a desired geometric shape. Mesh processing includes various operations which modify input mesh for specific purpose, which usually preserve overall shape or local details.

There are various methods to represent a 3D surface, such as NUBRS and implicit surface. Among these methods, polygonal mesh is a very popular one for game industry, for it is simple, flexible, and efficient. We introduce the modeling and processing of polygonal mesh, or, for short, mesh.

A mesh is composed of some basic elements: vertices (red dots), edges (black lines), and faces (light blue areas). Each vertex stands for a specific position in a 3D space, each edge connects two vertices, and each face is a surface patch bounded by a loop of edges. Theoretically, a face is bounded by any number of edges, but triangular and quadrilateral faces are the most common ones.

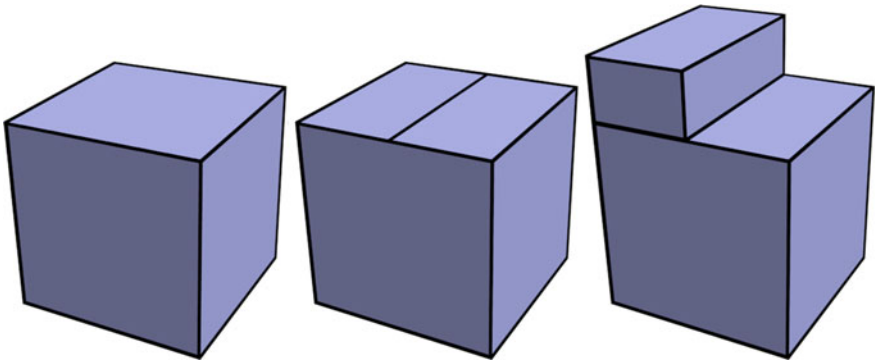


To model a surface by mesh, one can first create the vertices and then build the edges and faces. Such a very preliminary way is very inefficient. A widely applied method is to modify a simple mesh into a desired one by repeatedly applying several basic operations. Two of the most important operations are split and extrude. The split operation (center of the inset) cuts a face into smaller ones, and the extrude operation (right of the inset) builds a prism using an existing face as the base (Fig. 1). Other advanced modeling methods usually adopt other surface representations, such as NURBS and implicit surface, and then convert the modeling result into a mesh.

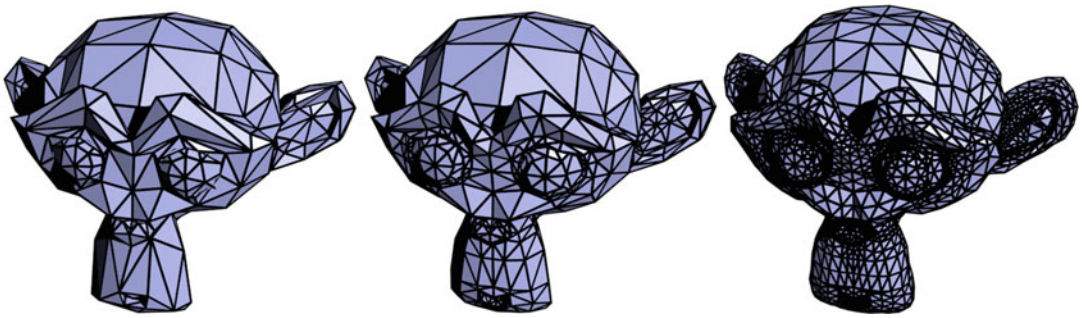
Mesh processing refers to applying certain operations on a mesh to turn it into a desired one. Thus, some modeling methods can also be viewed as mesh processing. For games, simplification (left of the inset) (Fig. 2) and subdivision (right of the inset) could be the most important processing over an input mesh (center of the inset), which adjust the mesh to balance the accuracy and performance.

Simplification turns a mesh into an approximated one with less number of faces, which sacrifices the quality to reduce the storage and rendering cost. The common strategy to simplify a mesh is to recursively remove basic elements (e.g., vertices, edges, or faces) in order. The order is critical and usually determined according to the error introduced by removing the elements. The error can be measured in many different ways. A typical measurement is named as "Quadric Error Metric," (Garland et al. 1997) which measures the change of geometric shape by an easy-to-compute quadric form in terms of the vertex positions. Other measurements could take the change of normal distribution, texture, and other factors into account. During the simplification, one could also apply application-dependent restrictions to the procedure, such as maximal edge length, minimal angle, and sharp feature preserving, etc.

On the contrary, subdivision increases the number of faces for better accuracy. It uses a set of topological rules to change and add more elements into a mesh and then put the updated vertices into certain positions according to geometric rules. Recursively refining a mesh can result in a sequence of mesh with finer and finer resolution. The limit one is smooth almost everywhere and tightly related to B-spline and other algebraic surface. The most simple and widely used subdivision schemes include Catmull-Clark (Stam



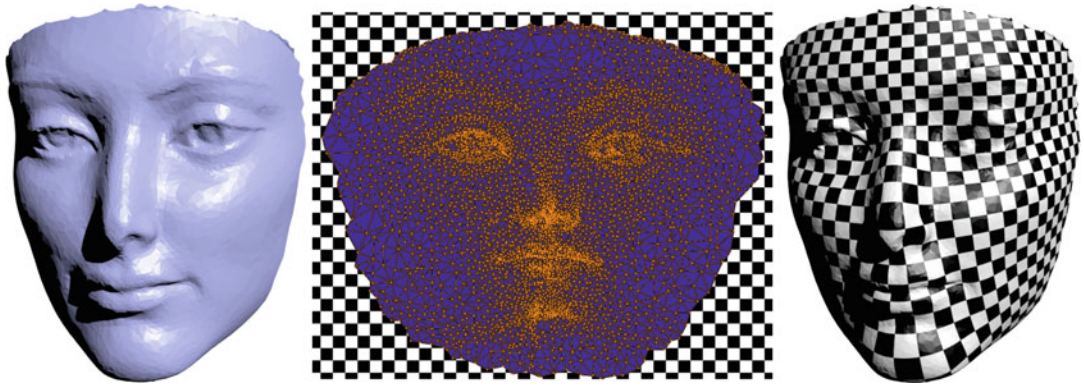
Modeling and Mesh Processing for Games, Fig. 1 starting from a cube (left), use split (middle) and extrude (right) operations to model a shape



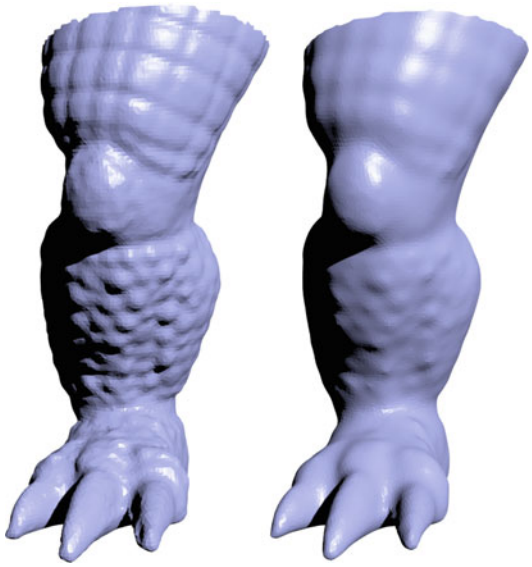
Modeling and Mesh Processing for Games, Fig. 2 Simplify (left) and subdivide (right) an input mesh (middle)

1998), Doo and Sabin (1978), and Loop (1987). The above subdivision schemes refine the mesh in a whole and may introduce too many elements unnecessarily. The adaptive subdivision strategy only refines part of the model that needs more elements. Modern graphics processing unit (GPU) is able to perform subdivision very efficiently. Therefore, to render a high quality surface, one can just send a simplified mesh with a small number of faces into GPU, and let GPU tessellate it into a high-quality mesh with a large number of faces. Integrating simplification and subdivision does not only help rendering, but can also be helpful in network environment.

Mesh processing also includes a lot of other operations, which does not change the topology but only changes the vertex positions, such as smoothing and enhancement. These two operations change the detail of the mesh but roughly keep its shape. Such operations view the shape represented by mesh as a signal and modify the high frequency part. Such types of mesh processing are usually related to Laplacian-based methods and tightly related to spectral analysis (Taubin 1995). For example, the smoothing operation reduces high frequency details from the input mesh (left of the inset), which is similar to a low-pass filter and results in a mesh with smoother shape (right of the inset). On the contrary, some of the mesh processing, such as deformation and animation, keep the detail but change the overall shape. Many state-of-the-art deformation and animation methods also found the base on Laplacian of the mesh and adopt many differential geometry concepts to characterize the "detail" to be preserved (Huang et al. 2006) (Fig. 3).



Modeling and Mesh Processing for Games, Fig. 3 parameterization turns a 3D surface mesh (left) to a 2D planar one (middle), which helps to map a texture image back to the mesh (right)



General mesh processing even includes some operations that neither change the topology nor geometry. Take parameterization as an example (Hormann et al. 2007), it computes a mapping (middle of the inset) from a planar domain to a mesh (left of the inset) so that a planar signal can be transported onto the mesh (right of the inset). Texturing is a typical application of parameterization, which enhances the appearance of a mesh by mapping an image onto the mesh.

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Model-View-Controller (MVC)

► Interactive Computer Graphics and Model-View-Controller Architecture

Monte-Carlo Tree Search

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Synonyms

MCTS; UCT

Definition

Monte-Carlo Tree Search (MCTS) (Coulom 2007; Kocsis et al. 2006) is a best-first search method that does not require a positional evaluation function. It is based on a randomized exploration of the search space. Using the results of previous explorations, the algorithm gradually builds up a game tree in memory and successively becomes better at accurately estimating the values of the most promising moves. MCTS consists of four strategic steps, repeated as long as there is time left (Chaslot et al. 2008b). The steps, outlined in Fig. 1, are as follows:

1. In the *selection step*, the tree is traversed from the root node downward until a state is chosen, which has not been stored in the tree.
2. Next, in the *play-out step*, moves are chosen in self-play until the end of the game is reached.
3. Subsequently, in the *expansion step*, one or more states encountered along its play-out are added to the tree.
4. Finally, in the *backpropagation step*, the game result r is propagated back along the previously traversed path up to the root node, where node statistics are updated accordingly.

Structure of MCTS

MCTS usually starts with a tree containing only the root node. The tree is gradually grown by executing the selection, play-out, expansion, and backpropagation steps. Such an iteration is called a full simulation. After a certain number of simulations, a move is chosen to be played in the actual game. This final move selection is based on the highest score or alternatively the number of times being sampled. The detailed structure of MCTS is discussed by explaining the four steps below.

Selection

Selection chooses a child to be searched based on previous information. It controls the balance between exploitation and exploration. On the one hand, the task consists of selecting the move that leads to the best results so far (exploitation). On the other hand, the less promising moves still have to be tried, due to the uncertainty of the simulations (exploration).

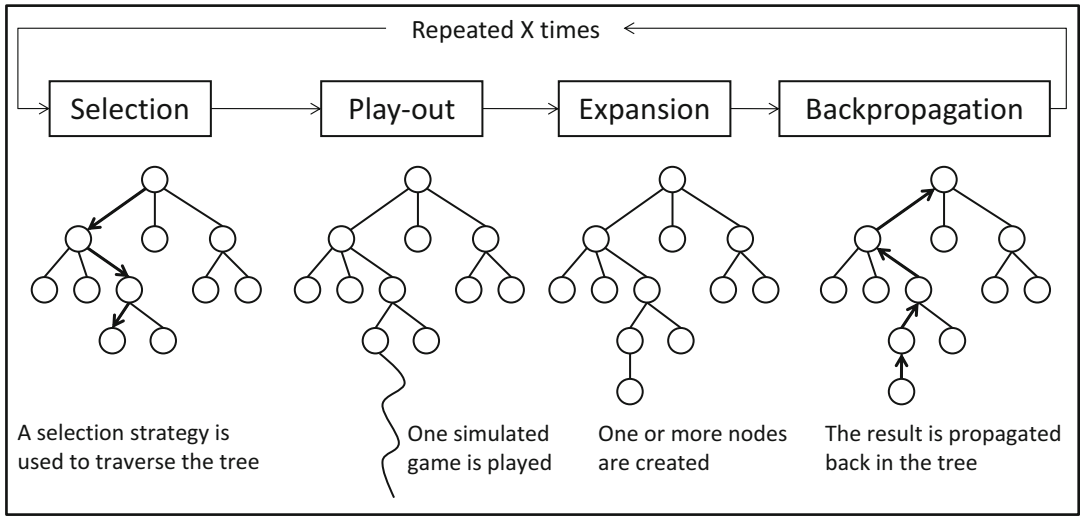
Several *selection strategies* (Browne et al. 2012) have been suggested for MCTS such as BAST, EXP3, and UCB1-Tuned, but the most popular one is based on the UCB1 algorithm (Auer et al. 2002), called UCT (**U**pper **C**onfidence Bounds applied to **T**rees) (Kocsis et al. 2006). UCT works as follows. Let I be the set of nodes immediately reachable from the current node p. The selection strategy selects the child b of node p that satisfies Formula 1:

$$b \in \arg\max_{i \in I} \left(v_i + C \times \sqrt{\frac{\ln n_p}{n_i}} \right) \quad (1)$$

where v_i is the value of the node i, n_i is the visit count of i, and n_p is the visit count of p. C is a parameter constant, which can be tuned experimentally (e.g., $C = 0.4$). The value of v_i should lie in the range [0, 1]. In case a child has not been stored in the tree or has not been visited yet, a default value is assumed. For example, the maximum value that a node could obtain by sampling (i.e., $v_{\max} = 1$) is taken.

Play-Out

When in the selection step a state is chosen, which has not been stored in the tree, the play-out starts. Moves are selected in self-play until the end of the



Monte-Carlo Tree Search, Fig. 1 Outline of Monte-Carlo Tree Search (adapted from Chaslot et al. 2008b; Winands et al. 2010)

game is reached. This task might consist of playing plain random moves or – better – semi-random moves chosen according to a *simulation strategy*. Smart simulation strategies have the potential to improve the level of play significantly. The main idea is to play interesting moves based on heuristics. In the literature this play-out step is sometimes called the roll-out or simulation.

Expansion

Expansion is the procedure that decides whether nodes are added to the tree. Standard the following *expansion strategy* is sufficient in most cases: one node is added per simulation (Coulom 2007). The added leaf node L corresponds to the first state encountered during the traversal that was not already stored. This allows to save memory and reduces only slightly the level of play.

Backpropagation

Backpropagation is the procedure that propagates the result r of a simulated game t back from the leaf node L, through the previously traversed nodes, all the way up to the root. If a game is won, the result of a player j is scored as $r_{t,j} = 1$, in the case of a loss as $r_{t,j} = 0$, and a draw as $r_{t,j} = 0.5$. To deal with multiplayer games, the result is backpropagated as a tuple of size N, where N is the number of players. For instance, if Player 1 and Player 3 both reach a winning condition in a 3-player game, then the result r is returned as the tuple $\left(\frac{1}{2}, 0, \frac{1}{2}\right)$. Propagating the values back in the tree is performed similar to $\max^n$ (Sturtevant 2008).

To compute the *value* v_i of a node i, a *backpropagation strategy* is applied. Usually, it is calculated by taking the average of the results of all simulated games made through this node (Coulom 2007), i.e., $v_i \leftarrow R_{i,j}/n_i$, where j is the player to move in its parent node p and $R_{i,j} \leftarrow \sum_t r_{t,j}$ the cumulative score of all the simulations.

MCTS Enhancements

Over the past years, several enhancements have been developed to improve the performance of MCTS (Browne et al. 2012). First, there are many ways to improve the selection step of MCTS. The major challenge is how to choose a promising node when the number of simulations is still low. Domain-independent techniques that only use information gathered during the simulations are Transposition Tables, Rapid Action Value

Estimation (RAVE), and Progressive History (Childs et al. 2008; Gelly et al. 2012; Nijssen and Winands 2011). Techniques that rely on hand-coded domain knowledge are, for instance, Move Groups, Prior Knowledge, Progressive Bias, and Progressive Widening/Unpruning (Chaslot et al. 2008b; Childs et al. 2008; Gelly et al. 2012). The used heuristic knowledge may consist of move patterns and even static board evaluators. When a couple of these enhancements are successfully incorporated, the C parameter of UCT becomes usually very small or even zero.

Next, the play-outs require a simulation strategy in order to be accurate. Moves are chosen based on only computationally light knowledge (Gelly et al. 2012) (e.g., patterns, capture potential, and proximity to the last move). Adding computationally intensive heavy heuristic knowledge in the play-outs (such as a 1- or 2-ply search using a full board evaluator) has been beneficial in a few games such as Chinese Checkers and Lines of Action. When domain knowledge is not readily available, there exist various domain-independent techniques to enhance the quality of the play-outs, including the Move-Average Sampling Technique (MAST), Last-Good-Reply Policy, and N-Grams (Tak et al. 2012). The principle of these techniques is that moves good in one situation are likely to be good in other situations as well.

The basic version of MCTS *converges* to the game-theoretic value, but is unable to prove it. The MCTS-Solver technique (Winands et al. 2010) is able to prove the game-theoretic value of a state with a binary outcome (i.e., win or loss). It labels terminal states in the search tree as a win or loss and backpropagates the game-theoretic result in a $\max^n$ way (Nijssen and Winands 2011). For games with multiple outcomes (e.g., win, loss, or draw), the technique has been extended to Score Bounded Monte-Carlo Tree Search (Cazenave and Saffidine 2011).

Finally, to utilize the full potential of a multi-core machine, parallelization has to be applied in an MCTS program. There exist three different parallelization techniques for MCTS: (1) *root parallelization*, (2) *leaf parallelization*, and (3) *tree parallelization* (Chaslot et al. 2008a). In root parallelization, each thread has its own MCTS tree. When the allotted search time is up, the results of the different trees are combined. In leaf parallelization, one tree is traversed using a single thread. Subsequently, starting from the leaf node, play-outs are executed in parallel for each available thread. Once all threads have finished, the results are backpropagated. When using tree parallelization, one tree is shared, in which all threads operate independently. For shared memory systems, tree parallelization is the natural approach that takes full advantage of the available bandwidth to communicate simulation results (Enzenberger and Müller 2010).

Historical Background

Classic search algorithms such as A*, $\alpha\beta$ search, or Expectimax require an evaluator that assigns heuristic values to the leaf nodes in the tree. The 15-puzzle and the board games backgammon, chess, and checkers are instances where this approach has led to world-class performance. However, for some domains constructing a strong static heuristic evaluation function has been a rather difficult or an even infeasible task.

Replacing such an evaluation function with Monte-Carlo sampling was proposed in the early 1990s. Abramson (1990) experimented with these so-called Monte-Carlo evaluations in the games of tic-tac-toe, Othello, and chess. In 1993 Bernd Brügmann was the first to use Monte-Carlo evaluations in his 9×9 Go program Gobble. The following years, the technique was incorporated in stochastic games such as backgammon (Tesauro et al. 1997) and imperfect-information games such as bridge (Ginsberg 1999), poker (Billings et al. 1999), and Scrabble (Sheppard 2002).

In the early 2000s, the Monte-Carlo approach received new interest in the Computer Go domain (Bouzy and Helmstetter 2004). Bruno Bouzy's Monte-Carlo Go engine Indigo had some limited success as the main challenge was to effectively combine Monte-Carlo evaluations with game-tree search. The breakthrough came when Coulom presented the MCTS approach at the 2006 Computers and Games Conference (Coulom 2007). He

subsequently demonstrated its strength by winning the 9 × 9 Go tournament at the 12th ICGA Computer Olympiad with his MCTS engine Crazy Stone. Simultaneously Kocsis and Szepesvári (Kocsis et al. 2006) introduced the MCTS variant UCT. Its selection strategy became the standard for many MCTS engines (Browne et al. 2012). Techniques such as RAVE, Prior Knowledge, Progressive Bias, and Progressive Widening (Chaslot et al. 2008b; Gelly et al. 2012) were needed to make MCTS effective in many challenging domains such as 19 × 19 Go. Parallelization (Enzenberger et al. 2010; Gelly et al. 2012) has enabled MCTS to compete with human Go Grandmasters. As of 2014, an MCTS engine can beat a 9-dan professional player with only a four-stone handicap, whereas a decade ago 20 stones could be given.

Applications

In the past few years, MCTS has substantially advanced the state of the art in several abstract games (Browne et al. 2012), in particular Go (Gelly et al. 2012), but other two-player deterministic perfect-information games include Amazons (Lorentz 2008), Hex (Arneson et al. 2010), and Lines of Action (Winands et al. 2010). MCTS has even increased the level in multiplayer games such as Chinese checkers (Sturtevant 2008) and games with stochasticity and/or imperfect information such as Kriegspiel (Ciancarini and Favini 2010), Lord of the Rings: The Confrontation (Cowling et al. 2012), and Scotland Yard (Nijssen and Winands 2012). In the General Game Playing competition, where an agent has to play many different abstract games without any human intervention, MCTS has become the dominant approach as well (Björnsson and Finnsson 2009).

Besides application to abstract games, MCTS has made inroads in the video game domain. It has been applied in the arcade game Ms. Pac-Man for controlling either the Ghosts or the Pac-Man (Nguyen and Thawonmas 2013; Pepels et al. 2014). The technique has been used for resource allocation and coordination in the turn-based strategy game Total War: Rome II and for tactical assault planning in the real-time strategy game Wargus (Balla et al. 2009). The MCTS framework has also shown promise in the General Video Game AI Competition (Perez et al. 2014), where the goal is to build an agent that is capable of playing a wide range of (simple) video games.

MCTS has also been applied in puzzle games such as SameGame (Schadd et al. 2012) where it is hard to design an admissible evaluation function for A* or IDA*. As these games are close to scheduling and optimization problems, MCTS has been introduced in real-life applications. They are, for instance, high energy physics (Ruijl et al. 2014), patient admission scheduling (Zhu et al. 2014), and interplanetary trajectory planning (Hennes et al. 2015).

Future Directions

MCTS does not require a positional evaluation function, overcoming partially the knowledge acquisition bottleneck. It is therefore a promising method when an agent has to play a wide range of games as is fostered in the General (Video) Game Playing competitions. However, for MCTS to work effectively, search-control knowledge is required to guide the simulations. Domain-independent techniques are able to boost the decision quality of an MCTS engine, but for achieving expert level hand-coded domain knowledge is incorporated to grasp high-level context. Instead of being hand-coded by the programmer, a future research direction is to automatically discover, extract, represent, and tune this control knowledge during online search.

MCTS has been quite successful in abstract games; however, the number of successful applications in modern video games with high fidelity is rather limited. There are three challenges for applying MCTS in these games. (1) In these video games, the action space is large if not infinite, and the state space is often continuous. For MCTS to work effectively, the game world has to be abstracted automatically in such a way that (i) the number of possible moves is limited and (ii) the number of moves required to finish the

game is reduced as well. (2) These games have a high degree of uncertainty, not only due to non-determinism (the outcome of a move cannot be predicted) or imperfect information (certain information is hidden for a player) but also because of incomplete information (the behavior of the physics engine may be unknown). For non-determinism and imperfect information, MCTS enhancements have been investigated to a limited number of abstract games (Cowling et al. 2012), but even less for video games. Dealing with incomplete information in the MCTS framework is a largely unexplored terrain. (3) Due to the real-time property the amount of deliberation time is limited. MCTS has to generate a sufficient number of simulations in a short time as otherwise the decision quality is quite low (Björnsson and Finnsson 2009).

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Motion and Posture Analysis

▶ Data Gloves for Hand and Finger Motion Interactions

Motion Capture

▶ Sketch-Based Posing for 3D Animation

Motion Matching

▶ Motion Matching: Data-Driven Character Animation Systems

Motion Matching: Data-Driven Character Animation Systems

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Synonyms

Distance Matching; Motion Matching

Definition

Motion matching is a data-driven technique for animating virtual characters in real-time with a high degree of realism. This method relies on a large set of preprocessed motion data, typically captured using motion capture devices. In a game loop, the motion matching system continually searches a motion database to find the most suitable short motion clip to fulfill the user's intentions and the game requirements. The chosen motion is then seamlessly blended with the currently playing character animation to create realistic transitions.

Introduction

Video games and other interactive applications are constantly striving for higher levels of graphical fidelity and immersion. While visuals are certainly important, the realism of the dynamic

interactions between characters and their virtual worlds may be even more crucial to achieving a sense of immersion. Therefore, animation systems play a vital role in modern game development. As graphics continue to evolve and become more detailed, there is a corresponding need for equally detailed world dynamics and animations. An effective animation system must be able to handle an increasing number of interactions and support the creation of rich virtual worlds.

Conventional animation systems, which rely heavily on hand-crafted state machines and parametric blending of animations, are not suitable for many scenarios because they do not scale well. Manually modeling every potential interaction with a state machine is impractical as the number of possible state transitions increases combinatorially. To address this issue, motion matching (Büttner and Clavet 2015) was developed as a data-driven animation technique that does not explicitly model every possible interaction. Instead, it searches an animation database for the most suitable short sequence for a given set of circumstances.

Motion matching has been widely adopted by game studios, including For Honor (Clavet 2016), EA Sports UFC 3 (Harrower 2018), The Last of Us 2 (Michal and Zhuravlov 2021), and Control (Ilkka and Ville 2021).

Character Animation

In order to create an animation system, a mathematical model of the character and its movements over time must be developed. This includes defining the foundational concepts and data structures used to represent character animations. Typically, animations are made up of discrete character poses that are stored and interpolated through as time progresses.

The central element in character animation is the affine transformation, which concisely describes a position and direction in an affine space. An affine transformation A is defined by a translation $p \in \mathbb{R}^3$ and a rotation $q \in \mathbb{S}^3$, both relative to an affine space. Affine transformations can also include a scale component, but in the case of human bones, which are rigid and of constant length, this component is typically assumed to be equal to one. For cartoony characters, the scale component could vary.

Equation 1 is used to compose an affine transformations A_0 over A_1. This equation first translates A_1 by rotating it with the q component of A_0 and adding the p component of A_0. It then computes the new orientation of A_1 by composing q_0 with q_1, effectively applying the two rotations in order.

$$\begin{aligned} p &= q_0 \times p_1 + p_0. \\ q &= q_0 \times q_1. \end{aligned} \tag{1}$$

Skeletal Mesh Animation

Virtual characters are typically represented using skeletal meshes, which consist of a set of polygons that make up the character's surface and a hierarchy of interconnected bones used to deform the polygons. The polygons are composed of vertices, and the way in which each bone influences the movement of the polygons it is associated with is determined by skin weights, which are assigned to each vertex of the mesh. This process, known as mesh skinning, is used to bind the character's surface to its bones. However, the specifics of mesh skinning are not covered here.

It is useful to model a chain of bones such that rotating a bone automatically applies the same rotation to its children. To do this, each bone i is modeled using an affine transformation $A_i^{I(i)}$ that is defined relative to the affine space of its parent $A_{I(i)}^{I(I(i))}$, where $I(i)$ is a function that maps bone i to its parent. This is achieved by applying the inverse transformation of the parent, $A^{I(i)}i = A^{-1}I(i) \times A_i$. The pose of a character at frame k is then represented as an ordered set of N affine transformations, $P_k = \left[A_{0,k}^W, A_{1,k}^{I(1)}, \ldots, A_{N,k}^{I(N)}\right]$. The root bone's affine transformation, A_0^W, is special and is defined relative to the coordinate system of the game world, as indicated by the W superscript.

The above construction has the property that translating the whole set of bones in the game world only involves translating A_0^W. However, when rendering the character, converting every relative transformations to the game world coordinate system is necessary. Each bone has exactly one parent, meaning that one can compute every world space affine transformations in a single

Motion Matching: Data-Driven Character Animation Systems, Fig. 1 The skeletal mesh of a freely available 3D model. (© Unity Technologies Japan/UCL) The multiple polygons composing the characters are delineated with black lines, and the bone hierarchy is displayed with red spheres and stripes

ordered pass starting from the root bone using forward kinematics. For example, if the bones with indices 1 and 2 have parents indexed as 0 and 1, respectively, the calculations will be $A_1 = A_0^W \times A_1^0$ followed by $A_2 = A_1 \times A_2^1$. (Fig. 1).

A skeletal mesh animation is therefore a sequence of character poses:

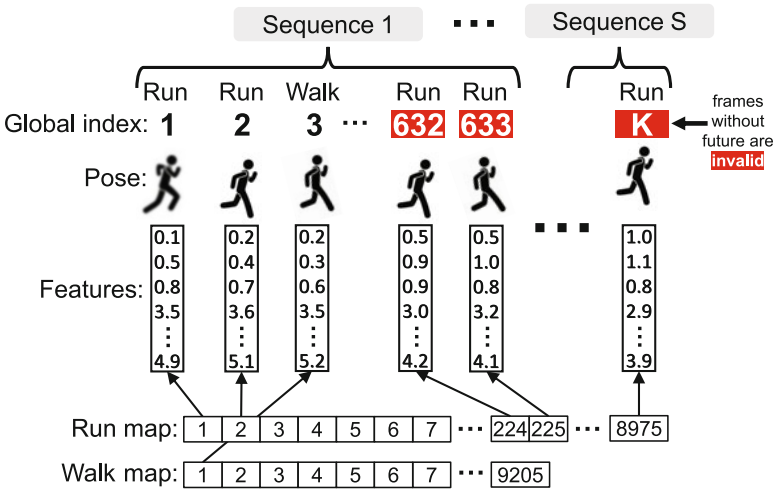
$$s = [P_0, P_1, \ldots, P_n] \tag{2}$$

where n is the number of frames in the animation. For simplicity, it is assumed that the animations are densely sampled at each frame and that the sample rate is equal to the application frame rate. Playing back an animation in this context is equivalent to flipping through the pages of a flipbook.

Motion Matching

Motion matching is a technique that works by defining the high-level goals of the animation system and searching a database for the short subset of an animation that best matches those goals. The system defines goals with concrete values such as the desired character position in 60 frames or the foot starting position at the start of the sought short sequence. This obtained pose sequence is then intelligently blended into the already playing animation. When the goals of the animation system are updated or a fixed interval of time has passed, a new search is performed to find an appropriate short pose sequence and blend it in. This continuous blending, coupled with the goal of minimizing the new sequence's disparity through the search process, is key to synthesizing smooth character motion.

To enable the search, the poses P_k of each animation sequence s are concatenated to form K consecutive frames. An algorithm is then used to search for a frame $k^* \in \mathbb{N} : k^* < K$ from which to start playing back a pose sequence. Figure 2 illustrates the database structure that contains a global index mapping to each existing pose. During the search, the selected frame k^* best conforms to the animation system's goals. To find the most similar frame, a set of numerical features that characterize the situation at each frame k is extracted and compared to query features, which encode the desired properties of the wanted sequence. Choosing the appropriate information to put in the



Motion Matching: Data-Driven Character Animation Systems, Fig. 2 Schematic of a motion database. All pose sequences are concatenated, forming K frames indexing an array of poses. Each frame is associated with a numerical feature vector that describes the situation at the frame. Also, a mapping per action in the dataset is maintained to search only a relevant subset of the data. Frames at the end of sequences are invalid as they have no defined future and therefore are not valid candidates to start playing back the animation

features, which consists of designing a query space, is fundamental to a working implementation of motion matching.

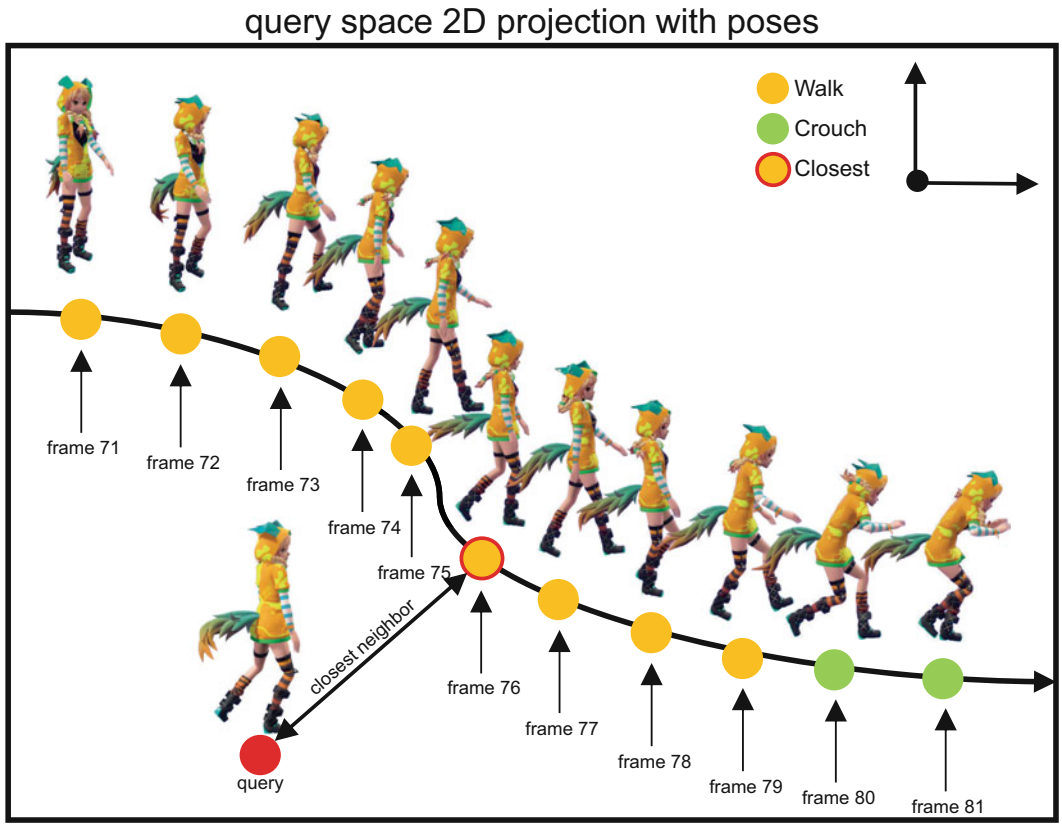
Section "Query Space" introduces concrete feature definition and usage, section "Search" presents the search algorithm, section "Blending" describes the motion blending procedure, section "Procedural Adjustments" introduce post-processing steps, and section "Making Queries" touches upon how to create the query features.

Query Space

The features reflect the high-level goals of the search because they specify the values that the searched motion sequence should approach. For example, by considering a character's in-game right foot position as a feature during the search, the system prioritizes motion that starts with the same right foot position. Similarly, by adding the in-game character's desired future right foot position as a feature, the search is steered toward selecting a motion that will move the right foot to that position. The first example is a pose-conserving feature, while the second example is a controlling feature. It is important to balance the influence of pose-conserving and controlling features to achieve an acceptable trade-off between responsiveness and smoothness. In Fig. 3, one can see how each frame of data forms a smooth trajectory in an hypothetical feature space.

Motion matching is essentially making search queries, and the design of the possible queries impacts the quality of the generated motion. It is necessary to have simple and general queries. To improve the generality of spatial features, they are encoded in a relative coordinate system based on the character's facing direction projected to the ground, which is called the character reference frame. The character reference frame is described with an affine transform ρ which can be applied to any transform as $\rho^{-1} \times A$ encoding A in the character reference frame. By applying ρ^{-1}, spatial features and pose sequences are made invariant to translations and rotations in the plane relative to the character. For example, the pose sequence and spatial features of a character walking forward in any cardinal direction are the same in the character reference frame since it is forward with respect to the character's direction. Thanks to the invariance provided by the character reference frame, it is not necessary to record a separate walking forward animation for every possible direction.

Each frame k in the database is associated with a pose and a set of numerical features. The j-th



Motion Matching: Data-Driven Character Animation Systems, Fig. 3 An hypothetical 2D query space made from the features of multiple frames of motion data and a query point. The frames form a discretized trajectory in the feature space and the distance between the query and each frame can be computed

feature at frame k is computed as $f_{j,\,k} \in \mathbb{R}$ where $j \in \{0, \ldots, J\}$ and J is the number of features. Concatenating every frame's features vertically forms the feature matrix F.

$$F = \begin{bmatrix} f_{0,0} & \cdots & f_{0,K} \\ \vdots & \ddots & \vdots \\ f_{J,0} & \cdots & f_{J,K} \end{bmatrix} \tag{3}$$

To account for the variable scales of the features (rows), the mean μ_j and standard deviation σ_j of each feature are computed, where $f_{j,k}$ is the j-th row and k-th column of the feature matrix F as shown below:

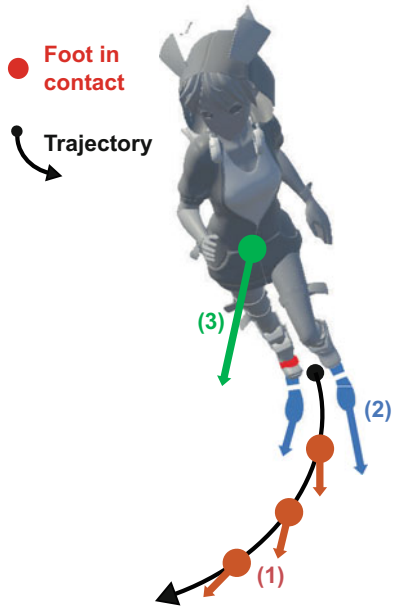
$$\mu_j = \frac{1}{K} \sum_{k=0}^{K} f_{j,k} \tag{4}$$

$$\sigma_j = \sqrt{\frac{1}{K} \sum_{k=0}^{K} \left(f_{j,k} - \mu_j\right)^2} \tag{5}$$

Each feature is also optionally tuned with a custom weight w_j yielding the final scaled feature as $d_{j,k} = \frac{w_j \times f_{j,k}}{\sigma_j}$.

Those feature are compared with a query vector $q = [d_{0,q}, d_{1,q}, \ldots, d_{J,q},]$ which is computed in real time from the game situation. Searching the best frame turns into a comparison between q and every scaled columns of F.

Holden et al. (2020) and Bergamin (2021) shared a set of spatial features found to be effective for locomotion. Figure 4 illustrates three conventional motion matching features. Firstly, steering and velocity control are achieved by matching the character reference frame positions



Motion Matching: Data-Driven Character Animation Systems, Fig. 4 An illustration of effective spatial features for locomotion extracted from frames of motion data. (1) A group of future positions of the character. (2) The positions and velocities of the feet. (3) The hip velocity. The group in (1) is made of control features, while (2) and (3) are pose-conserving features. Feet in contact with the ground are also marked for procedural adjustments

0.33, 0.66, and 1 second in the future relative to the current character reference frame. This matching compares candidate trajectories starting at every frame with the desired trajectory formed from a game-pad. Secondly, matching the character's current foot velocities and positions relative to the character reference frame maintain consistent foot placement and reduce foot sliding artifacts. Thirdly, matching the character's current hip velocity relative to the character reference frame stabilizes the character's orientation.

Search

The motion matching search is identical to finding the closest neighbor in the k-nearest neighbors algorithm (Holden 2018). The idea is straightforward; a transition cost between the query vector q and each frame's feature in the database is used to rank neighbors. Figure 3 illustrates the geometrical closeness of an hypothetical query vector with recorded features in a 2D feature space. The cost of one recorded frame is measured using Eq. 6, which calculates the squared distance with each feature vector.

$$c_k = \sum_{j=0}^{J} \left(d_{j,q} - d_{j,k}\right)^2 \tag{6}$$

In the end, the pose sequence associated with the frame with the lowest total cost $k^* = \arg\min_k c_k$ will be blended in. A variation proposed in Häfliger and Kurabayashi (2021) relies on a specific distance function per feature instead of a generic distance function, removing the need to compute the scaled features $d_{j,k}$ but instead normalizes the separate costs.

The search algorithm scales with the number of compared frames, leading to a trade-off between the amount of variation in the dataset and the retrieval speed. Fortunately, there is a lot of literature on optimizing the k-nearest neighbors algorithm to accelerate the search while guaranteeing a valid result. In most cases, only the frame with the minimum cost is relevant (closest neighbor), and it is not necessary to compute the exact score of each frame. To accelerate the search, the early out matching variation shown in Algorithm 1 can be used. This method involves skipping a candidate frame as soon as its partial cost sum exceeds the score of the current best frame.

Algorithm 1 Early out matching

Input: A reference to the motion database and the query vector

Output: The index of the pose sequence in the DB with the lowest cost, k^*

1: $d_{0,q}, d_{1,q}, \ldots, d_{J,q} \leftarrow$ *query vector*
2: $c^* \leftarrow c_0$
3: $k^* \leftarrow 0$
4: ***for*** $k = 1, 2, \ldots, K$ **do**
5: $c_k \leftarrow 0$
6: ***for*** $j = 0, 1, \ldots, J$ **do**
7: $d_{j,k} \leftarrow$ *motion database*
8: $c_k \leftarrow c_k + (d_{j,q} - d_{j,k})^2$
9: **if** $c_k > c^*$ **then**
10: *skip* to next k
11: **end if**
end for

12: **if** $c_k < c^*$ **then**
13: $k^* \leftarrow k$
14: $c^* \leftarrow c_k$
15: **end if**
end for
16: return k^*

Another conventional acceleration is achieved by pre-computing a hierarchy of bounding volumes per feature vector. The cost of the bounding volume is checked before the feature vectors inside the volume, skipping a majority of score computation when the bounds are well tuned. In practice, as hinted by the database layout in Fig. 2, only frames whose action corresponds to the current user-selected action are considered. During transitions, it is also advised to consider past actions. A mapping between actions and their corresponding frames is stored to enable this pruning of the search.

It is also possible to accelerate motion matching by tolerating some retrieval imprecision. Techniques such as quantization or dimensionality reduction applied to every $d_{j,k}$ can reduce the computational burden of the search. A dimensionality reduction technique, PCA (Pearson 1901; Hotelling 1933), diminishes the feature vector sizes by projecting them to a lower-dimension coordinate system. Consider a feature matrix $X \in \mathbb{R}^{K \times J}$ that contains K mean normalized feature vectors of J dimensions (one vector per row). PCA provides a projection matrix $W \in \mathbb{R}^{J \times J}$ composed of J eigenvectors ordered by their influence on the total variance of the projected features. A subset of the most influential columns of the projection matrix $W_L \in \mathbb{R}^{J \times L}$ where $L < J$ is extracted to project features to a lower-dimension coordinate system by applying the truncated transformation $X_{pca} = XW_L$. Despite the lousy projection, the projected features still conserve most of the variance of the non-optimized features. Furthermore, a quantization of the feature values, for example, by using a reduced number of bits, can also accelerate the speed; Büttner (2019) introduced such a scheme by encoding vectors with short codes. Finally, Holden et al. (2020) showed how deep neural networks could approximate the motion matching algorithm enabling constant inference time.

Blending

After the search, the optimal frame k^* from where to start playing back the pose sequence is obtained. However, if the new sequence is directly played, a noticeable jump in the character pose will be visible. One solution called cross-fading consists of interpolating toward the new sequence in a short period by gradually translating/rotating each bone position/rotation toward their new values. For human motion data, such interpolation produces natural transitions (Safonova and Hodgins 2005).

Assuming two sequences s^0 and s^1 of length n, each pose is merged using a *mix* function: $P_i = mix\left(P_i^0, P_i^1, \frac{i}{n}\right) \forall_i \in 0..n$, where mix applies a linear interpolation (Lerp) to each bone position and a spherical linear interpolation (Slerp) to each rotations. The factor $\frac{i}{n}$ controls the influence between the old and the new sequences, when $i = n$ only the new pose is considered. The Slerp and Lerp functions are described in Eq. 7 for positions p_0, p_1, quaternions q_0, q_1, and coefficient α.

$$\begin{aligned} Lerp(p_0, p_1, \alpha) &= (1 - \alpha) \times p_0 + \alpha \times p_1. \\ Slerp(q_0, q_1, \alpha) &= q_0 \left(q_0^{-1} q_1\right)^{\alpha}. \end{aligned} \tag{7}$$

Cross-fading is not preferred in practice, as it requires evaluating all blended sequences, which is resource intensive in scenarios where there may be more than two blended sequences. In complex games, the actual motion results from multiple procedural adjustments applied on top of the raw poses (Ilkka and Ville 2021), such as rotating the character's head toward a relevant object or enforcing that the character doesn't traverse a wall. Evaluating multiple sequences is too computationally expensive; therefore, Inertialization (Bollo 2018), which only requires the evaluation of the new sequence and often produces more natural transitions, is preferred. This technique works by interpolating between the source and target poses through an approximated smooth curve that considers the initial velocities of the source sequence joints and estimates suitable accelerations.

Procedural Adjustments

Motion matching is often limited by issues such as foot sliding due to the blending of dissimilar poses or the feet going through the ground in complex terrain. Adjusting the pose data of a found sequence to mitigate these artifacts and add other effects depends on the specific requirements of a game.

One approach to addressing issues with the feet is to mark each frame index k with two boolean values indicating whether the right or left foot is in contact with the ground. When playing a sequence in which a foot should be in contact, the system can use this information to ensure that the foot reaches the ground and does not move too much horizontally (on non-slippery surfaces). To accomplish this, the system can adjust the position of the foot to stay on top of the ground geometry beneath it. This can be achieved by performing a raycast, which involves shooting a virtual ray to detect the terrain geometry by finding the closest collisions. For a typical foot-knee-hip bone chain, the adjustment can be made by finding the knee and hip rotations that allow the foot to reach the desired location. In general, this problem of finding such rotations is known as Inverse Kinematics (Aristidou et al. 2018). There is an efficient closed-form solution for a two-joint kinematic chain in a fixed plane, and readers can refer to Holden (2017) for an intuitive derivation.

Making Queries

To be effective, the animations played back by motion matching must be of high quality and include sufficient variations to cover a wide range of gameplay scenarios. Traditionally, motion clips are recorded through motion capture, either by having the actor perform a precisely orchestrated choreography or by allowing them to move freely and randomly. Structured and unstructured motion clips can both be useful in this context. Because of the vertical symmetry of the human body, the data can be mirrored to reduce the number of necessary takes by half in well-planned sessions. However, it is difficult to anticipate and capture every possible transition, so unstructured takes can also be useful in filling in the gaps. Finally, designers can mark valid frame sequences in the data to remove duplicates, fix poor acting, and customize the system's runtime behavior.

In addition to having high-quality data, it is also important to generate query features that correspond to the recorded features, or the matches will be of poor correspondence. Pose-conserving features can be used as-is, since they are already derived from previously played back data. Control features, on the other hand, can be more challenging to craft, as they must approximate natural human locomotion while being generated from a game controller. One common approach is to simulate the evolution of a spring to generate natural and parameterized future trajectories. Holden (2021b) presents live examples and rigorous derivations of such spring simulation for games. The spring behavior can be tuned through multiple parameters to match the desired control scheme and generate appropriate queries.

Conclusion

This entry delves into the use of motion matching techniques in character animation systems for video games. It presents a mathematical description of motion matching, the main components of a motion matching-based animation system, and practical guidelines followed by industry practitioners.

Motion matching synthesizes responsive, smooth motion by selecting the most appropriate animation subsequence for the current game situation and blending it with the currently playing animation. The construction of the query space, a retrieval space that separates potential starting points of animation subsequences through featurization at each frame, is a key element of the algorithm. By comparing recorded frame features with features constructed at runtime, it is possible to find the closest frame of animation from which to start blending. Forming queries that match the data and the prepared query space is crucial to achieve satisfactory motion smoothness and responsiveness.

Those interested in learning more about motion matching techniques can refer to (Bergamin 2021) for a thorough mathematical definition, (Häfliger and Kurabayashi 2022) and (Holden et al. 2020) for implementation details, and (Holden 2021a) for a standalone open-source implementation.

Cross-References

► Character Animation Scripting Environment

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Motion Planning in Computer Games

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Introduction

Planning motions of characters is necessary in some computer games because of several reasons. Positions of existing obstacles or opponents change, making predefined paths unsuitable.

New obstacles may be introduced in the gaming environment unpredictably, making motion planning necessary. Position of goal, like the treasure to be seized, may change unpredictably, making motion planning indispensable. Even if it is possible to predefine paths that are guaranteed to remain collision-free in some games, motion planning is needed to synthesize diverse paths to avoid predictability and unnatural motion. Some games have too many moving characters to predefine paths for, and motion planning is important for them even if they are nonplaying characters because they enhance player experience. Even if there are very few moving characters, there may be too many combinations of motion constraints to be satisfied at different times, making precomputation of motion plans infeasible. Other reasons for motion planning include expansion of the gaming environment enabled by portals, different speeds of characters, and multiple locomotion modes of characters. In some computer games, the challenge lies in deciding where to move next and not how to move there. In some computer games, the challenge lies in finding how to move to goal and not selecting goal. Some of the references in this article do not describe a computer game, but some ideas in them are usable in computer games. The emphasis of this article is on representative heuristics, strategies, tactics, challenges, geometric and logical representations, types of constraints to be satisfied, and evaluation metrics in motion planning in computer games and not on physics of motion and algorithmic details.

Terminology

Degrees of freedom: The number of degrees of freedom (DOFs) of a moving agent is the minimum number of parameters whose values need to be specified to completely specify the position and orientation of each part of the agent with respect to a fixed coordinate system.

Desirability map: It shows the desirability of visiting individual locations in a gaming world. The desirability is usually computed by combining the values of attributes related to direct or indirect or delayed or immediate reward and punishment.

Navigation mesh: A navigation mesh is obtained by partitioning the free space into convex polygons or polyhedrons, commonly referred to as *cells*. A collision-free path can then be found by searching a graph capturing connectivity of these cells and joining subpaths contained in these cells.

Roadmap: In the context of motion planning, a roadmap is a graph such that each of its vertices is a configuration of a moving agent like a point robot and each edge represents transition from one configuration to another through movement. If a roadmap is connected and is stored for future use, a path from an initial configuration to goal configuration can be found by connecting each of them to some vertex in the roadmap, instead of finding from scratch.

Waypoints: They are points between start and goal configurations used to guide an agent's navigation.

Voronoi diagram: Given a two-dimensional shape and a set of n points called *seeds* or *sites*, its Voronoi diagram is a collection of points partitioning the shape into n regions such that all points in each region are at least as close to one seed as any other seed.

Generalized Voronoi diagram (GVD): Given a shape S with shapes inside it, like a polygonal boundary with polygons within it, the GVD of S is the collection of points such that each of these points is equidistant from at least two shapes in S closest to it.

Medial axis: The medial axis of a shape is the set of centers of largest balls that can fit inside the shape such that each ball meets the boundary of the shape only tangentially at least two points. The medial axis changes if the object is deformed.

Motion clip: It is a short video containing motion of one or more objects.

Motion graph: A vertex of a motion graph is a motion clip or component of a motion clip. An edge of this graph represents that a transition from one clip to another is possible, making compound motion possible by joining motion clips connected by the edge. The graph can have cycles.

Motion database: A motion database used for computer animation contains motion clips.

Inverse kinematics: It is a process which finds positions and orientations of parts of a moving agent which ensure that a specific subsystem of the agent (usually the end effector like a gripper) is in the desired configuration.

Sampling-based motion planning: It is a paradigm which involves creating samples (geometric configurations) of the moving agent, randomly or with a bias, and connecting them to create a roadmap which is used for finding a collision-free path.

Motion Planning for One Agent

Motion planning for one agent is relevant when there is only one moving agent or there are multiple agents that move fully independent of each other without having to worry about collisions among them, but collisions with nonmoving objects are to be avoided. Kovar and others (Kovar et al. 2002) introduced motion graphs for efficient composition of motions to create compound motions. Rahim and others (Rahim et al. 2009) report on creation of motions for animated characters using motion graphs derived from motion clips from a motion database. These motion clips contain running, walking, jumping, and other types of movement. They review distance metrics used to find similar poses in clips to find transitions possible between motion clips or their components, to establish the edges of a motion graph. The virtual agent in (Rashidian et al. 2014) has to visit at least one goal from each of the k groups of goals, starting from the given initial configuration in presence of static obstacles. This is referred to as *multigroup motion planning* in (Rashidian et al. 2014). Their approach includes finding a tour for the virtual agent without considering obstacles and using sampling-based motion planning to consider obstacles. Their experiments included a ground vehicle and an aerial vehicle. The digital mannequin in (Arechavaleta et al. 2004) has 53 degrees of freedom. It is composed of 20 rigid bodies connected by 18 joints. The object carried by the mannequin has 6 degrees of freedom. Since it is extremely hard to find a collision-free path for a system with 59 degrees of freedom, the system is first treated as a 9-DOF system by constraining the configurations of the mannequin and the object. Once a collision-free path is found, the frozen parts of the system are animated in a collision-free manner to create a natural motion.

The path planning approach in (Juarez-Perez and Kallmann 2018) associates a clearance, preference, and cost with each behavior. They consider three behaviors – (i) frontal walking, (ii) constrained frontal walking, and (iii) lateral walking or sidestepping. Arms are relaxed during frontal walking, but this behavior needs higher torso clearance. Frontal walking is the most preferred behavior and costs the least. Constrained frontal walking needs lower torso clearance, costs more, and is less preferred. Lateral walking is the least preferred behavior among the three, costs the most, but needs the least clearance, making it indispensable for navigation through narrow passages. For efficiency, their approach doesn't check for collisions between certain obstacles (like short obstacles) and torso of the moving character since such collisions are impossible. Their layered approach initially finds a collision-free path using the costliest behavior (sidestepping) which is also the least preferred behavior and needs the least clearance. The layered approach then tries to reduce the path cost by improving the initial path using more preferred behaviors which also cost less and need higher clearance. The path planning approach in (Kapadia et al. 2013) handles hard and soft constraints. Each soft constraint has a weight showing how important its satisfaction is. Satisfaction of hard constraints is mandatory. Satisfaction of soft constraints is optional. Some of the nodes and edges in their hybrid state-transition graph are obtained by partitioning the free space into triangles in a specific way. Some nodes and edges in this graph are obtained by laying a uniform grid over the free space such that a node in the grid has up to eight neighbors. Some nodes and edges in this graph are obtained by laying triangles over the free space for

representing spatial relations satisfying spatial constraints on a path. Examples of spatial relations include an agent being on the right or left of an object or in the line of sight of a patrolling guard. Nodes and edges added to the hybrid state-transition graph because of triangular cells and their adjacency allow faster synthesis of paths and reduction in path length. Nodes and edges added to the graph by uniform grid allow synthesis of paths satisfying diverse constraints.

It is pointed out in (Lee et al. 2006) that capturing motion data in a physical environment and adapting it to a virtual environment is a bottleneck in computer animation. This is because creating or renting complex/specialized physical environments and having humans perform various actions in them and creating digital approximations of real environments and real characters can be time-consuming and pricey. They propose a data-intensive scalable approach in which a complex virtual environment is composed of small units and the motions in this environment are composed of the motions associated with these small units, e.g., a large playground can be created by populating it with curved slides and straight slides, and complex motion in this environment can be composed of walking, climbing, and sliding motions. A *building block* (also known as a *motion patch*) in their work consists of an environment-building unit like a curved slide and specific motions available with it. Motions available in an environment-building unit are reusable in a copy of it. Their approach is usable for multiple agents too. They report that an office environment can be generated using a desk-chair combo and square ground panel. The motion patches for an office environment they identified based on 40 minutes of motion are (i) sitting down or standing up, (ii) working at a desk, (iii) chatting at a desk, (iv) standing idle at a place away from all desks, (v) chatting at a place away from all desks, (vi) disputing at a place away from all desks, (vii) making a presentation while standing away from all desks, and (viii) walking and then stopping. Instead of generating an environment with obstacles and then finding collision-free paths in it, the approach in (Lee et al. 2006) offers a combo of an environment and collision-free motion, significantly reducing or eliminating the computational complexity of motion planning because motion planning is then needed only for characters or environment not based on motion clips. It is possible to compose character motions and then include nonmoving objects in a manner that avoids motion conflicts.

Motion Planning for Adversaries

The motion planning approach suitable when there are adversaries depends on their count, separation distance possible, speeds, directions of movement, and other constraints like staying visible to nonplaying agents, if any. Park and others (Park et al. 1997) present a computer game containing two boxing robots such that one of them is controlled by the human player and the other is computer-controlled. The human player's arm movements are tracked with 3D position sensors attached to wrists and elbows. The motion planner for the computer-controlled boxer finds offensive motions to hit the human-controlled boxer and defensive motions to prevent being hit on its hittable surface. The motion planner samples the position of fist of the human-controlled boxer at a fixed frequency and uses it along with passage of fixed time without a punch from the human-controlled boxer to decide whether to be offensive or defensive. Hittable areas of each robot are two predefined rectangles which are discretized assuming that there are finite hit points. Blocking a punch with a forearm is the only defense strategy. The motion planner computes the ratio of the distance from the defending forearm of the human-controlled boxer and the distance from the hitting fist of the robot-controlled boxer for individual exposed hittable points on the human-controlled boxer and targets the point with highest ratio during offense. Inverse kinematics is used for motion planning.

Shamgah and others (Shamgah et al. 2016) present an abstract model in which the attacking robot tries to move to reach its target cell in a grid with the defending robot trying to move to capture

the attacking robot. The number of strategies for each player in this reach-avoid game is the number of cells it can move to next. The payoff for the defender for strategy combination (i,j) is $e(a_i, t)/e(a_i, d_j)$ where function e is the Euclidean distance between its arguments, a_i is the cell in which the attacker will end up by following strategy i (same as moving to cell i), t is the target cell the attacker is trying to reach, and d_j is the cell in which the defender will end up by following strategy j (same as moving to cell j). The attacker wants to move to minimize this payoff. The defender wants to move to maximize this payoff. This model can be realized in computer games in multiple ways, e.g., having one attacker and one defendant with multiple target cells that vanish if not reached in cell-dependent time, having multiple attackers and one defendant, having one attacker and multiple defendants, and allowing an attacker to be captured a certain number of times. Instead of generating the payoff matrix with all strategy combinations to guide the movement of computer-controlled characters, a partial payoff matrix with randomly chosen strategy combinations can be used. This will not only be computationally efficient, but it will also often result in suboptimal choices for computer-controlled characters which will make them more believable and boost the morale of the human player by increasing his/her chance of winning.

Motion Planning for Crowds

Li and others (Li et al. 2017) present an implemented and evaluated hybrid approach to model motions of agents in a crowd. In an agent-based approach to crowd simulation, each agent is autonomous. In cellular-automaton approach to crowd simulation, agents have no autonomy at all. In the hybrid approach in (Li et al. 2017), each agent is autonomous and has a positive tolerance value which is the number of time steps for which it can wait in its current cell before moving to the next cell. When multiple agents want to move to the same cell, the agent which waited the longest in its current cell has the highest probability of moving to the cell. The crowd simulation model in (Liu and Chen 2008) allows different types of agents. Their implementation has many birds, deer, and tigers. Besides having different speed and acceleration, they exhibit different behaviors. Birds fly or rest. Deer wander, march toward goal, or evade tigers. Tigers wander, trace deer, and attack. There is a finite-state machine (FSM) for each kind of animal. The FSMs specify conditions for transition between behaviors.

The main objective of the crowd simulation approach in (Chang and Li 2008) is maintaining the shape of the crowd, e.g., a square or convex nonagon. Opposing troops in a battle can form different shapes. Their approach first generates a path for the shape representing the crowd. If needed, the shape is deformed to avoid obstacles. Individual agents exhibit different behaviors within the shape, e.g., changing or maintaining speed or orientation or staying still. A gamified approach to crowdsourced design of floor plans is presented in (Chakraborty et al. 2017). Human players don't plan motions of characters. They design floor plans by choosing the locations and numbers of doorways, walls, and pillars, starting with the layout provided by an architect or designer. A player can change density of crowd and distribution of agent speed, acceleration, and agent width and height. After designing the floor plan, a human player can run simulation which ends after evacuation of the environment is complete. Players are ranked based on evacuation time. This work can be viewed as a way to verify that motion planning and execution meeting certain constraints is possible in the given environment. By running simulations with different parameters, one can find how motion-friendly an environment is. Some approaches to crowd simulation involve guiding the moving characters along medial axis or the edges of a Voronoi diagram or a GVD or some other type of roadmap. Though this can result in slow movement of characters due to waiting and make motion look unnatural and predictable, it makes collision avoidance easier. The approach in (Oliva and Pelechano 2013) dynamically generates waypoints for characters with different radii to avoid these problems.

Conclusion

Motion planning in computer games has used some of the advances in robot motion planning, computational geometry, computer animation, and search in artificial intelligence. Still, high computational complexity associated with large state spaces and loss of completeness and optimality typically associated with scalable motion planning techniques is inherited by computer games using these techniques. There is scope for research on modifying techniques and representations used in robot motion planning and search in artificial intelligence, using the freedom to include fiction in computer games.

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M

Motion Tracking

► Tracking Techniques in Augmented Reality for Handheld Interfaces

Motivation

► Videogame Engagement: Psychological Frameworks

Motor Disability

► Computer Games for People with Disability

Movie-Making of Spatiotemporal Dynamics in Complex Systems

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Synonyms

The art of electroencephalography

Definitions

Electroencephalography, or **EEG**, is an electrophysiological monitoring device comprised of multiple electrodes (small, flat, metal discs with thin wires) placed on the scalp that send signals to a computer in order to noninvasively measure and record electrical activity on the scalp. **EEG** can be used in cognitive research or to diagnose conditions such as epilepsy and sleep disorders.

Biofeedback systems are computerized devices that provide information about the activity of physiological measures, such as heart rate variability, in order to learn how to modulate at will specific body functions to improve energy management, health, self-mastery, and general well-being. Biofeedback systems may include EMG machines, ECG, heart rate variability, respiration, and EEG among others.

Heart rate variability (HRV) is a measure of the patterns prescribed by inter-beat intervals of time and the functioning of the heart. **HRV** has been described as a psychophysiological biomarker to assess coherent or stressful states associated with respiration, cognition, and emotions (McCraty et al. 2009).

Psychophysiological coherence has been widely described as a state conducive to optimal cognitive performance, improved health and also associated to inner balance, peace, and harmony (McCraty et al. 2009).

Introduction

This entry describes the development and use of the art of movie-making in order to display spatiotemporal dynamics in complex systems such as brains. This qualitative tool has been used in visualizing, analyzing, and understanding brain dynamics as a new form of the art of encephalography (Davis et al. 2015; Davis and Kozma 2013). This tool has also been applied in order to visualize individual heart rate variability (HRV) in group dynamics in the study of psychophysiological coherence and its relationship to inner peace and social harmony (Davis et al. 2018; Heart Coherence Ratio per Participant 2018). It would be possible, in principle, to apply this method to study any complex system that can be described as an array of signals that comprises a region of a system, which can be described as a whole in itself, for example, regions of the visual cortex.

This comes as a new and more advanced way to display images with the purpose of visual discrimination associated with the different brain cognitive states or heart coherent states, for example, in order to better understand and formulate theories of different stages of cognitive processes related to the creation of knowledge and meaning, intentional action, and value-based decision making (Davis and Kozma 2013; Davis et al. 2015a; Kozma and Davis 2018). The movies allow us to visualize different patterns of behavior in different conditions produced by different stimuli based on experimental data. By careful observation of each of these movies, the researcher learns to identify different structures and visual patterns where, for example, large-scale synchronizations and desynchronizations can be observed across different frequency bands (Davis et al. 2013; Myers et al. 2014).

Overview of the Methodology

A thorough description of this methodology, particularly applied to brain data, has been presented in previous work (Davis et al. 2015) together with an introduction to the different costs and benefits associated to it in terms of time consumption (hours

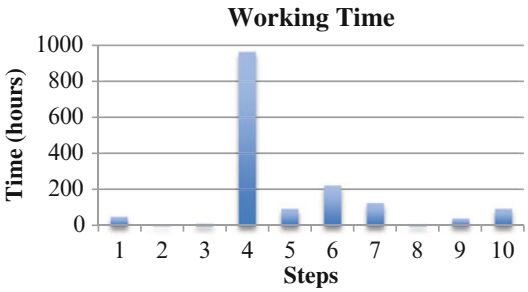
of work). Generally speaking, in order to more efficiently produce a greater amount of movies from brain data, for example, the more man and computer power is required. However, with a fair amount of people, like a team of two (2), and two (2) relatively powerful laptops, a considerable amount of movies can be made. It is important to note that in "The Art of Encephalography to Understand and Discriminate Higher Cognitive Functions Visualizing Big Data Imaging Using Brain Dynamics Movies" (Davis et al. 2015), 39 experiments (runs) in 4 bands for 4 indices (signals), for a total of 624 individual movies, were produced for a total work time of around 1623 h, which equates to around 10 or 5 months (1623 h) with 1 or 2 fulltime analysts, respectively, each working 5 days a week for 8 h a day. To illustrate this, it is important to note that the methodology is comprised of ten (10) steps as follows:

Step 1: Signal preprocessing and movie generation (~52 h)
Step 2: Movie downloads to computer (~4 h)
Step 3: Organization and editing of projects (~13.3 h)
Step 4: Synchronization of different runs or experiments into one movie that displays them all at the same time (~960 h)
Step 5: Corrections and art editing (~96 h)
Step 6: Rendering and further editing (~224 h)
Step 7: Exporting edited movie (~128 h)
Step 8: Finalizing corrections and speed calibration (~8 h)
Step 9: Final rendering (~42 h)
Step 10: Exporting and publishing final movie to website (~96 h)

The distribution of the workload across all steps is presented in Graph 1. Note that, Step 4 together with Step 6 are the major time-consuming activities requiring manpower skills, and therefore, in order to cut that time, more people, computers, software, and working space are needed.

Movie-Making and the Art of Encephalography via EEG Measurements

These movies allow researchers to explore the temporal evolution of spatial patterns where they can identify, in the case of brain dynamics, the different stages in the manifestation of, for example, a hypothesized cycle of creation of knowledge and meaning. These types of studies have been conducted both in animals and humans to capture brain dynamics in response to salient stimuli (Davis and Kozma 2012; Kozma et al. 2012), as well as the study of brain dynamics in different cognitive states (Davis et al. 2016; Davis et al. 2017).



Movie-Making of Spatiotemporal Dynamics in Complex Systems, Graph 1 Working time per step in the movie-making methodology

Movie-Watching and Pattern Recognition

It is conjectured that movie viewing will allow a better understanding of learning, adaptation, and cognition in general, by allowing researchers to familiarize themselves with very distinct patterns of the behavior of a complex system, like, for example, group coherence and synchronization between individuals in different group activities (McCraty 2017; McCraty et al. 2017; Timofejeva et al. 2017). In the case of cognition and consciousness, many of the philosophical implications associated with intentional behavior and value-based decision-making that have been published (Davis et al. 2015a; Davis et al. 2017; Kozma and Davis 2018) highlighted the value of using brain dynamics movies in the uncovering of different cognitive states and the cycle of creation of knowledge and meaning.

Further Comments on the Art of Encephalography

In summary, it can be said that viewing brain dynamics movies will allow a significant impression of brain events for different measurements, brain events across bands and the different stages

of the cycle of creation of knowledge and meaning, as well as the design of better monitors and biofeedback systems that will have to meet the challenge of efficiently processing large amounts of data online. With that in mind, many researchers interested in the study of consciousness and cognition, for example, will be able to discuss their insights after watching brain dynamics movies in a set of iterative brainstorming sessions. One can imagine and be positive that this kind of activity and approach will allow the emergence of better theories about brain functions, cognition, and consciousness in general. It is important to note that this way of visualizing brain dynamics has been inspired by the work of Walter J. Freeman who was a great pioneer and luminary of systems neuroscience.

Methodology and Applications

Usually complex systems are represented as a set of signals or time series which share a certain correlational or causal structure, and when viewed independently as a collection of plots over the same time axes, a substantial amount of information related to the spatial configurations and patterns that arise in each moment or time step (t) is lost. In order to capture the spatiotemporal dynamics, the need arises to display the signals, $x_i(t)$ with $i = 1,2,\ldots N^2$ in a new configuration, as follows:

$$X_{ij}(t) = \begin{pmatrix} x_1(t) & x_2(t)\ldots x_N(t) \\ x_{N+1}(t) & x_{N+2}(t)\ldots x_{2N}(t) \\ x_{2N+1}(t) & x_{2N+2}(t)\ldots x_{3N}(t) \\ \vdots & \vdots \\ x_{7N+1}(t) & x_{7N+2}(t)\ldots x_{N^2}(t) \end{pmatrix}_{NxN}$$

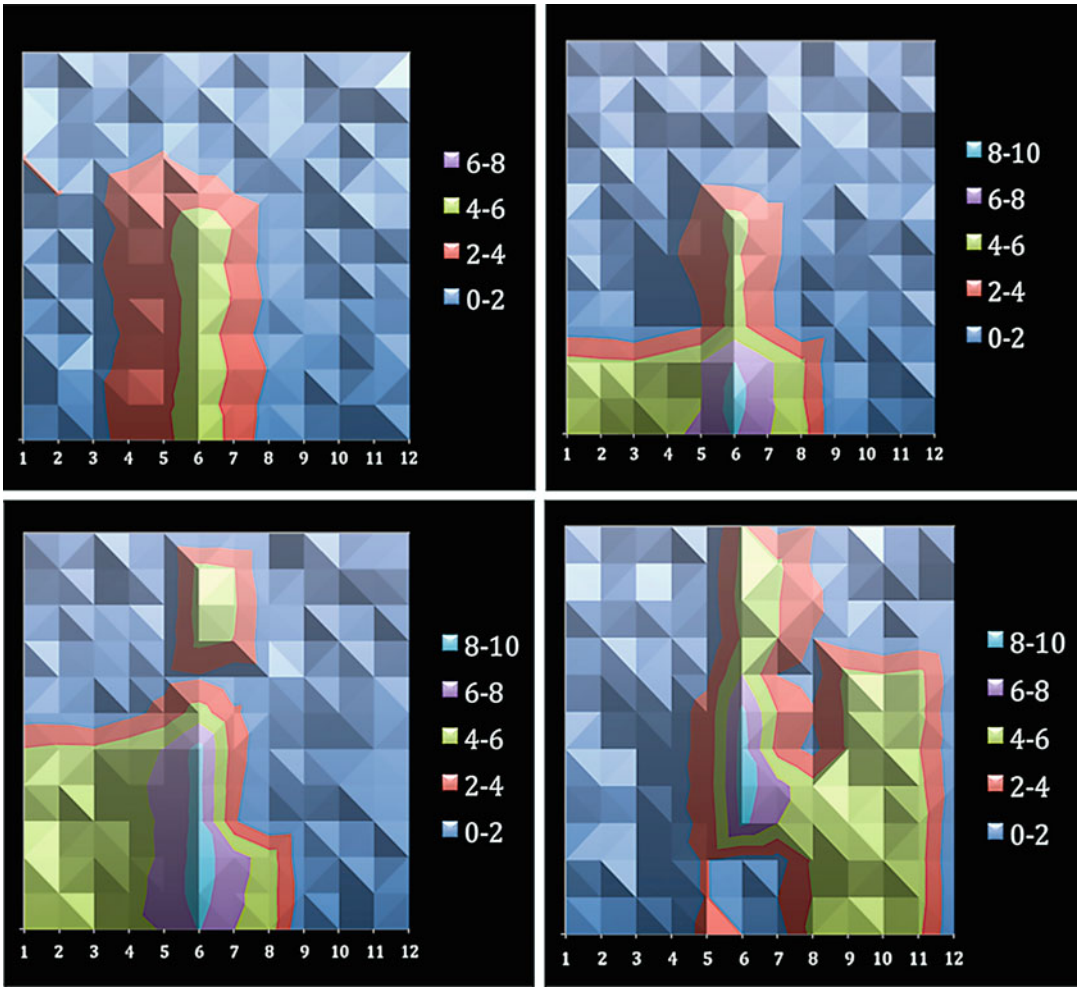
or

$$X_{ij}(t) = \begin{pmatrix} X_{11}(t) & X_{12}(t)\ldots X_{1N}(t) \\ X_{21}(t) & X_{22}(t)\ldots X_{2N}(t) \\ X_{31}(t) & X_{32}(t)\ldots X_{3N}(t) \\ \vdots & \vdots \\ X_{N1}(t) & X_{N2}(t)\ldots X_{NN}(t) \end{pmatrix}$$ for every time step t.

One can imagine every element of this matrix to be a pixel or a point to be displayed in a surface plot. If one assigns a color to each point and displays the surface in each time step (t), then the color patterns may reveal an orderly movement. When this set of surface plots is captured as frames of a movie and they are played at a certain speed, then the emergence of a spatiotemporal pattern may be observed. An example could be a simulated set of signals that could represent electrodes implanted on the cortex of an epileptic patient, in order to measure brain activity via ECoG. The following fictional example portrays a square array of 12×12 as if it was placed on the cortex of a patient with epilepsy, similar to the ones described in recent studies (Heck et al. 2016). The simulated patterns that emerge could look like the following sequence of surface plots in different moments of simulated data plotting amplitude values in the range of [0,10], as in Fig. 1.

Similar to the above simulated signals, recent studies using this methodology have shown that spatiotemporal brain dynamics could be tracked in terms of amplitude modulation patterns that could reveal responses to stimuli (Davis and Kozma 2013; Davis et al. 2013). This same methodology could be applied to brain dynamics measured on the scalp of a human, where the electrodes are placed all over the scalp and their associated signals are displayed for each point in the matrix, in each time step (t). In recent studies, the dominant frequency band (theta, alpha, beta, or gamma) has been studied under different cognitive modalities and these kinds of movies were used to track changes in the dominant frequency band (representing brain dynamics) for each part of the cortex (Davis et al. 2016, 2017). Figure 2 depicts two (2) moments where the change in the dominant frequency band can easily be appreciated for the arrangement of electrodes placed on the scalp that were obtained in the study just cited before (Davis et al. 2017). The displays show a spatiotemporal landscape related to one participant, in one particular time, in one particular modality (EEG Dunedin Movies 2018).

Similar movies can be developed based on studies of group dynamics using the heart rate



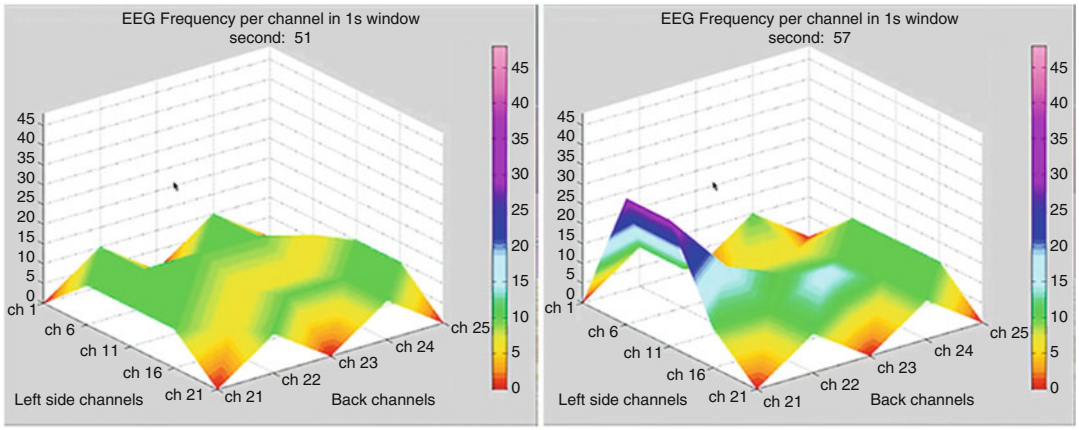
Movie-Making of Spatiotemporal Dynamics in Complex Systems, Fig. 1 Simulated signal amplitudes (144) placed in an imaginary 12×12 array showing 4 different consecutive times and the evolution of the system for t = 0 (top left), t = 1 (top right), t = 2 (bottom left) and t = 3 (bottom right)

variability (HRV) or a coherence ratio measure of each participant as the signal to be displayed in each time step (t), showing a group spatiotemporal landscape as shown in (Davis et al. 2018; Heart Coherence Ratio per Participant 2018) (Fig. 3).

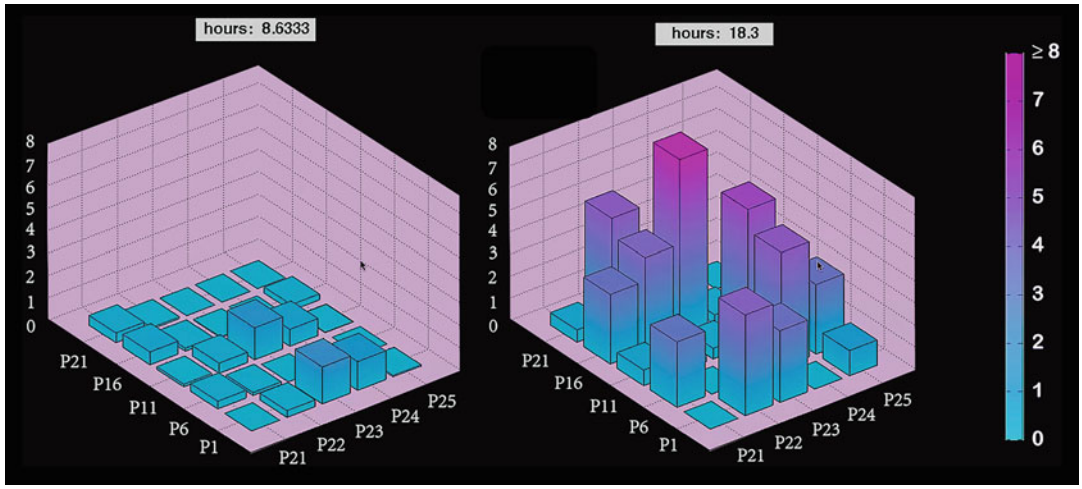
It is important to note that these kinds of studies with the aid of complex systems movies, like brain dynamics movies, could assist in the understanding of consciousness associated to different cognitive states, as in meditation and relaxation, or energy-consuming activities like reading difficult material, revealing different patterns in both brain and HRV dynamics (Davis et al. 2017; Davis and Kozma 2018). Studies conducted in recent years using this methodology have shown that brain dynamics associated with intentional behavior have their foundation and are deeply rooted in the creation of knowledge and meaning that takes place in mind-brain dynamics (Davis et al. 2015a; Davis 2018; Kozma and Davis 2018).

Conclusions and Future Perspectives

A methodology has been presented for displaying signals related to complex systems like brains and



Movie-Making of Spatiotemporal Dynamics in Complex Systems, Fig. 2 Displays of the dominant frequency band for 19 electrodes that cover the scalp and are arranged in a 5×5 array where six (6) dummy electrodes are anchored in zero (red), showing two (2) different moments in the evolution of human brain dynamics for t = 51 s (left) and t = 57 s (right)



Movie-Making of Spatiotemporal Dynamics in Complex Systems, Fig. 3 Display of the HRV coherence ratio for twenty two (22) participants in two (2) different activities over an array of 5×5 where three (3) positions (23, 24 and 25) are left in zero (0). **Left:** Baseline activity around 8:36 a.m. (low group coherence) and **Right:** A group meditation activity around 6:20 p.m. (high group coherence)

communities among others, where the displays are turned into movies based on sequential frames, where the evolution and dynamics of the system can be qualitatively studied in space and time. The challenges associated with the production of these movies are various, requiring efficient big-data processing algorithms and computer technologies that minimize the latencies between frame displays. This will ideally allow good quality movies, very close to online times biofeedback system displays. These kinds of new technologies could facilitate an efficient and comfortable qualitative interaction between computers and humans through brain-computer interfaces, where humans can presumably learn to modulate their own internal cognitive and psychophysiological states and in so doing, minimize stress and improve well-being. The use of this

methodology can be foreseen in the study of cognition and consciousness by increasing the experimental database that is derived from EEG measurements on the scalp of human participants under different modalities presumably leading to different cognitive states. It also can be conjectured that with a careful visual and statistical analysis (qualitative and quantitative), researchers will be able to uncover the intrinsic relationship between signals associated to respiration and brain-heart dynamics. It has been shown that human beings can generate psychophysiological states which are reflected in HRV and that are conducive to cognitive clarity and stress reduction (Heck et al. 2017). It is likely that in the future, the use of this methodology in the implementation of biofeedback systems will assist human beings in the mastery of inner peace, general well-being, and social harmony, where ideally one will be able to self-monitor heart-brain-respiration and other physiological signals almost in online time (minimal latency) and all signals at the same time.

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MR

▶ Interaction with Mobile Augmented Reality Environments

Multicolor Rainbow Hologram

▶ Holography as an Architectural Decoration

Multiculturalism

▶ Diversity in Gaming and the Metaverse

Multiplayer Cooking

▶ On Computer Games About Cooking

Multiplayer First-Person Shooter

▶ Destiny and Destiny 2, an Analysis of an FPS

Multiplayer Game

▶ Disney Toontown Online, a Massively Multiplayer Online Role-Playing Game
▶ Fantasy XVI Online, a Massively Multiplayer Online Role-Playing Game
▶ Overwatch: Team-Based Multiplayer First-Person Shooter Game
▶ World of Tanks, MMO Strategy Freemium Game

Multiplayer Games

▶ Sociality of Digital Games

Multiplayer Online Game, MOG

▶ Peer-to-Peer Gaming

Multiplayer Online Gaming Architecture

▶ Online Gaming Architectures

Multiplayers

▶ Game Prosumption

Multiuser Virtual Environment (MUVE)

▶ Virtual World, a Definition Incorporating Distributed Computing and Instances

Multi-user Virtual Environments for Education

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Synonyms

3DMUVE: Three-dimensional multi-user virtual environment; HUDs: Head-up displays; LSL: Linden script language; MMORPGs: Massively-multiplayer online role-playing games; MOOs: MUD, object-oriented; MUDs: Multi-user dungeons; OpenSim: OpenSimulator

Definition

Multi-user virtual environments (MUVEs) are structured with three-dimensional objects, in which users can actively navigate their avatars to different areas of the immersive environment.

OpenSimulator (OpenSim) is an open source multi-platform and multi-user 3D application server.

Introduction

Online multi-user virtual worlds have been used since the late 1970s (Achterbosch et al. 2007; Shield 2003). Initially, these environments were text-based interaction called multi-user dungeons (MUDs). With the transformation of MUDs to MOOs (MUD, object-oriented), users started to modify these worlds (Tüzün 2006). Advances in information and communication technologies have driven the MOOs' evolution, resulting in diverse human computer interfaces such as multi-user virtual environments (MUVEs) and massively-multiplayer online role-playing games (MMORPGs) (Dieterle and Clarke 2009). Newer generations of these environments are called immersive virtual worlds or metaverses (Dalgarno and Lee 2010). All of these virtual worlds are displayed online in three-dimensions (3D), and users can move and interact in simulated 3D spaces (Dickey 2005) that can be changed and modified. Users are represented as modifiable 3D avatars that can interact with other 3D avatars and do many activities such as walking, flying, running, jumping, and dancing. Avatars can be designed based on a user's real-life appearance or imaginary appearance (Fig. 1).

Three-dimensional multi-user virtual environments (3D MUVEs) can be used for different purposes such as socializing, entertainment, education, or business. A number of opportunities offered by 3D online virtual environments compared to 2D equivalents have led to great expectations, especially in the field of education. Using 3D MUVEs for education has the potential to create a constructivist learning environment where learners' interactions and communications using avatar-to-avatar activities can challenge them to figure things out for themselves (Educause 2006). Social organizations formed in 3D virtual microenvironments might make a significant contribution to learners' self-perception and moral values in the light of personal and social values. In this respect, 3D MUVEs seem to be well suited not only for cognitive and psychomotor learning areas but also for supporting affective learning (Barab et al. 2005; Bers 2001). Spatial knowledge representation provided by 3D MUVEs contributes to designing authentic learning environments, creating opportunities for experiential learning or learning contexts, and providing a rich learning experience that includes more effective collaboration and increases students' participation and motivation (Dalgarno and Lee 2010). In addition, students are encouraged to exhibit active involvement and learn by experience using applied activities (Coffman and Klinger 2008). 3D MUVEs contain teaching and learning activities such as problem-based

Multi-user Virtual Environments for Education, Fig. 1 Avatar examples for 3D MUVEs

learning, inquiry-based learning, game-based learning, role-playing, virtual quests, collaborative simulations, collaborative construction, design courses, language teaching and learning, virtual laboratories, virtual fieldwork, and attending classes (Duncan et al. 2012).

These environments' educational potential is summarized as follows (Kluge and Riley 2008; Freitas and Veletsianos 2010; González et al. 2013; Papachristos et al. 2014; Antonio et al. 2015; Dad et al. 2016):

- It reorganizes and extends social interactions and collaborations.
- It provides a free environment for learning.
- It supports active participation or "learning by doing" via authentic learning activities.
- It increases learner engagement, motivation, collaboration, and communication.
- It presents new opportunities and additional scope for creativity in learning such as role-playing and mentoring.
- It supports deeper learning by embedding simulations that are difficult to replicate in the real world including buying, selling, constructing buildings, dancing, clubbing, and even learning and training.
- It opens up new learning spaces and customized environments for rehearsal and exploration, experimentation and design, production, and user-generated content.
- It provides broader capabilities for learner-led activity as well as problem-based and exploratory learning.
- It provides learners with interaction via text, voice chat, or some animation movements.
- It offers remote access.
- It allows creation of a parallel world without limits to creativity and possibilities as the financial, spatial, and material constraints and the laws of physics are not applicable.

Three-Dimensional Multi-user Virtual Environments for Authentic Learning

3D MUVEs can be used for pedagogical classroom activities that are costly, complex, and even dangerous for learners and educators. 3D MUVEs offer opportunities to design authentic learning environments that focus on real-world complex problems and their solutions, using role-playing exercises, problem-based activities, case studies, and participating in virtual communities of practice

(Lombardi 2007). Herrington et al. (2002) identified ten characteristics of authentic learning environments:

- Authentic activities have real-world relevance.
- Authentic activities are ill-defined, requiring students to define the tasks and sub-tasks needed to complete the activity.
- Authentic activities comprise complex tasks to be investigated by students over a sustained period.
- Authentic activities provide the opportunity for students to examine the task from different perspectives, using a variety of resources.
- Authentic activities provide the opportunity to collaborate.
- Authentic activities provide the opportunity to reflect.
- Authentic activities can be integrated and applied across different subject areas and lead beyond domain-specific outcomes.
- Authentic activities are seamlessly integrated with assessment.
- Authentic activities create polished products valuable in their own right rather than as preparation for something else.
- Authentic activities allow competing solutions and diverse outcomes.

3D MUVEs represent a powerful media for instruction and have the ability to adapt to different learner needs (Mascitti et al. 2012). In addition, they can provide innovative ways to create challenging tasks in context (Iqbal et al. 2010). Thus, they can act as venues for authentic learning. Learners are part of a constructed environment and are engaging with the simulated environment, which is similar to real-life interactions (Farley 2016). There are some 3D MUVEs that allow designers and users to design a virtual environment such as Worlds.com (1994), Active Worlds (1995), Traveler (1996), Whyville (1999), Moove (2000), Second Life (2003), There (2003), IMVU (2004), Kaneva (2004), vSide (2006), OsGrid (2007), Smeet (2007), Smallworlds (2007), PlayStation Home (2008), Twinity (2008), Blue Mars (2009), and Onverse (2009) (Pearce et al. 2015; Tüzün and Özdinç 2016). Users utilize these environments for different purposes such as education, business, and entertainment. They may not always be appropriate for education because of user safety concerns, and authorization is limited to a user's land and avatar. In addition, there is a fee to customize some of these environments. In these cases, the open source platform called OpenSimulator can be used to create custom 3D MUVEs without fees or limitations.

OpenSimulator

OpenSimulator (OpenSim) written in C# is not a virtual world. It is an open source multi-platform, multi-user 3D application server to create your own virtual world (OpenSimulator 2017a) released under the BSD License. It provides the ability to customize and design virtual worlds for developers. OpenSim has features to support developers and users including:

- It runs on both a localhost and server using the Windows and Unix/Linux operating systems.
- It supports personal computers as a server.
- It supports online, multi-user 3D environments from one to thousands of simulators.
- It supports different sizes of 3D virtual spaces.
- Users access the same world at the same time.
- It supports real-time Physics Simulations.
- It supports users creating or modifying 3D content in real time.
- It supports using scripting including LSL (Linden Script Language)/OSSL and C#.
- It supports different database engines such as SQLite, MySQL, and MSSQL to store all content.
- It supports instant messaging by friends or groups.
- It supports loading different modules for configuration settings.
- It supports using external or internal VoIP services such as Freeswitch or Vivox.

The latest version of OpenSim was released on August 15, 2017 to users. However, some public distributors, such as diva distribution, add their own

modules and configurations and later share their repackaged OpenSim with users through the BSD license. It contains the standard OpenSim plus add-ons that support more features and tools that make the process of running and upgrading the virtual world easier (Diva 2013). Running in diva distribution is easier than OpenSim binary packages.

OpenSim can be started in stand-alone or grid mode. Stand-alone mode refers to operating all the data services in a single process when run as one or many regions. On the other hand, grid mode refers to using separate machines when multiple OpenSim instances run on different machines. Running in grid mode is more complicated than running in stand-alone mode (OpenSimulator 2017b). According to the number of users and intended use of the virtual worlds, the technical specifications for computers and servers will be different. For example, if a server is used for 20–25 users who perform tasks in virtual worlds, the following specifications will be sufficient:

- CPU: 4 Dual-core
- RAM: 8GB
- Bandwidth: If 20 users log in simultaneously, 10 MB/sec is necessary because each avatar or a user will use a minimum of 500 KB.
- Network Latency: Pings between the client and server should be better than 350 ms. It is important and critical on both upload and download to the simulator. It will affect avatar movement and object or avatar position changes.

If a server is used for 30–34 users who design in virtual worlds at the same time with VoIP, the technical specifications for the computers and servers must be improved. In addition, the number of objects used is a critical issue for these environments so storage capacity is important for designers. According to this example, the following specifications will be sufficient:

- CPU: 20 GHz
- RAM: 32 GB
- HDD: 300 GB SAS 10 K
- Bandwidth: Unlimited, 1000 Mbps Uplink

OpenSim provides an unlimited ability to customize virtual world applications easily with scene plug-in modules, although it is a highly complex system (OpenSimulator 2017c). Some of these plug-ins are for the startup of virtual worlds such as the region management plug-in. Other plug-ins are responsible for extending the functions of the virtual worlds such as voice or the effect of clouds and fog (Sun et al. 2010).

After the installation process, a viewer must be install as a user interface that allows users to modify or add connection settings to grids. The most popular of these viewers are Firestorm, Singularity, Cool VL, Kokua, Alchemy, and Radegast Metaverse Client (OpenSimulator 2017d). Most of these viewers are available for Windows, Linux, and MacOSX systems. A default avatar and an empty island will be displayed in the viewer in the first uploaded environment (Fig. 2).

After installation, OpenSim offers unlimited possibilities for users and designers based on their level. User powers are determined by User Level and Title (OpenSimulator 2017e).

- If a user's level is 0, the user is defined as default without any permissions.
- If a user's level is 1, the user may rename objects without modifying permissions.
- If a user's level is 100, the user may toggle character geometry, take copy, set to linden content, claim public land, and take ownership of an object.
- If a user's level is 150, the user can enable land auctions.
- If a user's level is 200 or 250, the user has full powers in the virtual world.

Initially, users' characters, called avatars, are displayed in the default view. However, they have an inventory and appearance options. Users can customize their avatars' shape, skin, hair, eyes, clothes, etc. and design their avatars' outfit.

OpenSim supports file formats and extensions as follows:

- Video: Flash (.swf), QuickTime (.mov), AVI (.avi), Mpeg (.mpeg), and RealNetworks Stream (.smil)
- Audio: MP3 (.mp3), WAV (.wav)
- Text: Text (.txt)

Multi-user Virtual Environments for Education, Fig. 2 OpenSimulator default context on viewer

- Image: Bitmap (.bmp), Jpeg (.jpeg), Mpeg (.mpg, .mpeg), Portable Networks Graphics (.png), Macintosh PICT (.pict), Silicon Graphics (.sgi), Graphics Interchange Format (.gif), Targa (.tga), and Tagged Image File Format (.tiff, .tif)
- 3D Model: Digital Asset Exchange (.dae), COLLADA (COLLAborative Design Activity), and Extensible Markup Language (.xml)
- Compressed files: Compressed TAR Archive file (.tgz), OpenSimulator Archive (OAR), and Inventory Archives (.iar)
- Animation: Biovision Hierarchy Animation File (.bvh, .anim)

3D objects are designed using basic objects called prims such as a cube or cylinder. Authorized users create prims, determine their position, scale, movement, and rotation, and combine them. Prims have different features:

- General: Object's name and description, owner, and permissions.
- Object: Object's x-y-z location, rotation, size, type, and physical features.
- Features: Object's light cast and flexible path.
- Texture: Textures can be 2D images or web contents on 3D objects.
- Content: All objects have the ability to store script or animation files.

Avatars interact with 3D objects and other avatars by touching them or script triggered behaviors. In addition, Head-Up Displays (HUDs) are useful objects for interaction. These objects can be attached to an avatar to create custom interfaces on a user's screen. Some interactions, messages, or textures can be added in the 2D view on HUDs.

OpenSim provides many opportunities for authentic learning utilizing customized virtual environments. The National Aeronautics and Space Administration (NASA) sponsored one of the largest projects with OpenSim, Virtual Missions, and Exoplanets (vMAX), between 2014 and 2017. vMAX developed a 3D virtual world using OpenSim to engage middle school students and educators. The overall project goal was to create a comprehensive NASA resource to engage students, educators, and the public in the search for worlds beyond Earth. In addition, it aimed to increase student engagement in STEM (Science, Technology, Engineering, and Mathematics), knowledge of exoplanet missions, and awareness of NASA-related careers (NASA n.d.). In this project, STEM includes astronomy and physics, technology such as telescopes and satellites, and

the engineering process and mathematics as applied to orbits and measurements. In addition, participants learn about exoplanets and related methods of detection as well as investigate via authentic learning activities using 3D MUVEs. Their avatars look like an astronaut and they complete tasks.

Conclusion and Discussion

3D immersive technologies, which initially came into daily life with modern computer games, have attracted research interest in the education field because of their pedagogical affordances such as enhanced learner engagement, motivation, and positive attitudes together with their openness to explore, design, and manipulate 3D objects. Today, there are increasing attempts to use 3D virtual learning environments in both face-to-face and distance learning settings to provide learners with more realistic and authentic learning environments.

OpenSim is an open source platform for building MUVEs. Unlike development platforms that offer ready-made services for accessing 3D spaces and 3D objects that can be used in these areas, OpenSim offers designers more manipulative design environments where all users can access the same design environment synchronously. Designers can also create 3D tools and objects that can be shared with other designers. Designers can modify shared 3D elements easily in accordance with their purposes. In addition, user security is high in OpenSim because of the use of private servers that are not accessible to everyone. It is important to know how to integrate pedagogy into these environments as well as how to use 3D environments created with OpenSim. However, the lack of guidance on how to organize instructional design elements and pedagogical arrangements in 3D MUVEs is a major limitation for educators.

Cross-References

▶ Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

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Multivariate Visualization Using Scatterplots

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Synonyms

Scatter chart; Scatter diagram; Scatter graph; Scattergram; Scatterplot

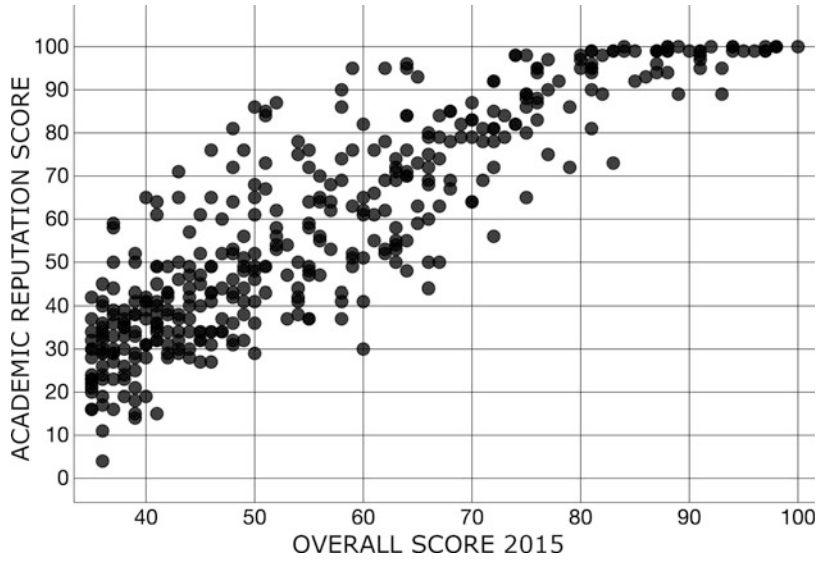
Definition

Multivariate visualization by scatterplots is the usage of diagrams to visualize sets of data that have more than three variables.

A scatterplot is a chart or mathematical diagram displaying a set of data as a collection of points using Cartesian coordinates, usually defined by horizontal and vertical axes. Each point on the chart represents two variables, x and y, calculated independently to form bivariate pairs (x_i, y_i). A functional relation between x and y is not necessary. The purpose of a scatterplot is to reveal (if existing) the relation between the displayed variables.

Introduction

Multivariate visualizations deal with the challenge of displaying sets of data with three or more variables: this peculiar feature poses two kinds of problems. First, most of the charts and diagrams usually adopted to visualize data cannot display more than three dimensions adequately.



Multivariate Visualization Using Scatterplots, Fig. 1 An example of scatterplot diagram

Second, the effectiveness of the visual effects adopted to represent different variables deteriorates when the number of variables increases.

Scatterplots may be considered, among the different types of data visual representations, as one of the most useful and versatile, especially in statistics. According to (Miller 1995), the term first appeared as Scatter Diagram in a 1906 article in *Biometrika*, "On the Relation Between the Symmetry of the Egg and the Symmetry of the Embryo in the Frog (*Rana temporaria*)" by J. W. Jenkinson. However, the term only came into wide use in the 1920s when it began to appear in textbooks, e.g., F. C. Mills, *Statistical Methods* of 1925. The Oxford English Dictionary gives the following quotation from Mills: "The equation to a straight line, fitted by the method of least squares to the points on the scatter diagram, will express mathematically the average relationship between these two variables." Fig. 1 provides an example of scatterplot diagram.

Scatterplots are mainly appreciated for their ability to reveal nonlinear relationships between variables. Moreover, scatterplots are typically used to identify correlations between variables, with a certain confidence interval. Another usage for the scatterplot is to compare similar data sets. Since the main problem of multivariate data is to correctly understand and analyze them, pointing out relationships, patterns, or outliers, a scatterplot provides a suitable visualization tool for multivariate data due to its intrinsic features.

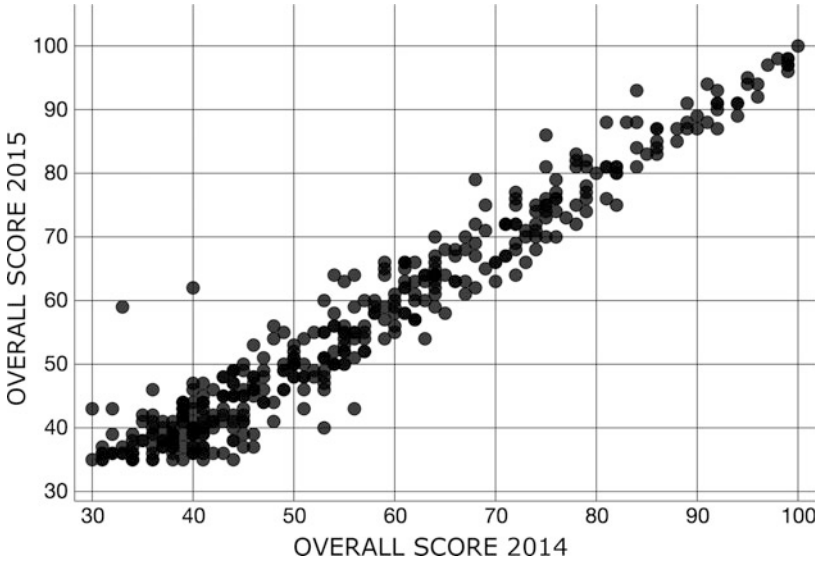
Usage

Different scenarios lead to different tasks when dealing with multidimensional visualization techniques. As defined by Valiati (2005) and further described by Pillat et al. (2005), five major tasks can be considered as objectives a user might want to fulfill when using a visualization tool to display or analyze multivariate data: identify, determine, compare, infer, and locate. Scatterplots can be used to assess all these different tasks and have been applied to data in many different fields of use, such as automotive, finance, pharmacology, environment, weather forecast, telecommunication, food, and many others.

Identify

This task refers to any action of finding, discovering, or estimating visually:

- Properties like symmetrical or asymmetrical distribution, values or dispersion
- Correlation, data dependency or independency
- Similarities or differences



Multivariate Visualization Using Scatterplots, Fig. 2 This scatterplot suggests a correlation between the two displayed variables

- Clusters as a result of similarity, continuity, proximity, or closed shapes
- Thresholds, patterns, data variation

The identify task takes place anytime the user analyzes the chart with the purpose of finding, estimating, or discovering new information about the data. The task ends when the user finds the information he/she was looking for or the current goal changes. Figure 2 shows an example of scatterplot that clearly suggests a linear correlation between the displayed variables.

Determine

This task corresponds to the action of calculating, defining, or precisely designating values such as:

- Mean, median, variance, standard deviation, amplitude, percentile
- Sum, differences, proportions
- Correlation coefficients, probabilities, or other statistics such as hypotheses test

This task begins when the user needs to calculate a specific value and ends up when the calculation is completed. Figure 3 shows a scatterplot that allows to derive the precise value of each point in order to compute precise calculations such as the mean value.

Compare

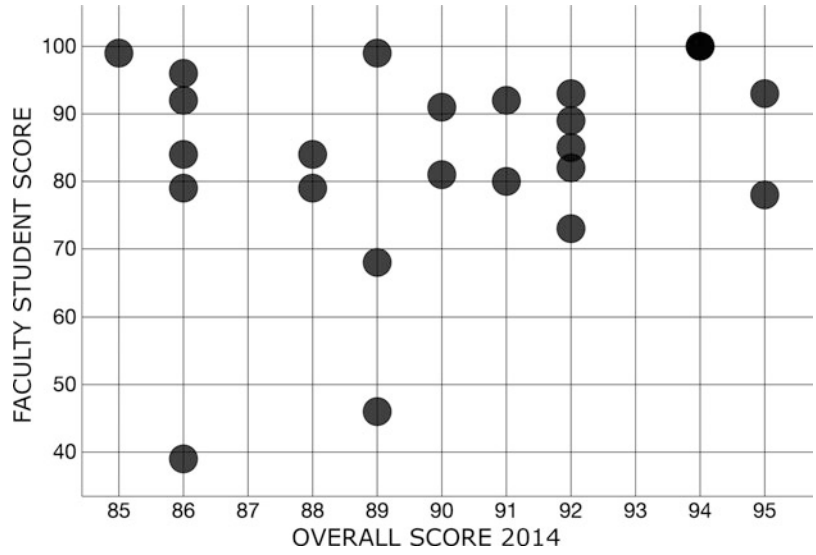
This task takes place when the user wants to compare data that have been previously identified, located, visualized, or determined. The user may compare data to analyze dimensions, data items, clusters, properties, proportion, values, locations and distances or visual characteristics. The compare task is an analytic task the user performs specifically if he/she compares data items displayed in the graphical visualization. Figure 4 shows a scatterplot configuration that enhances the comparison task.

Infer

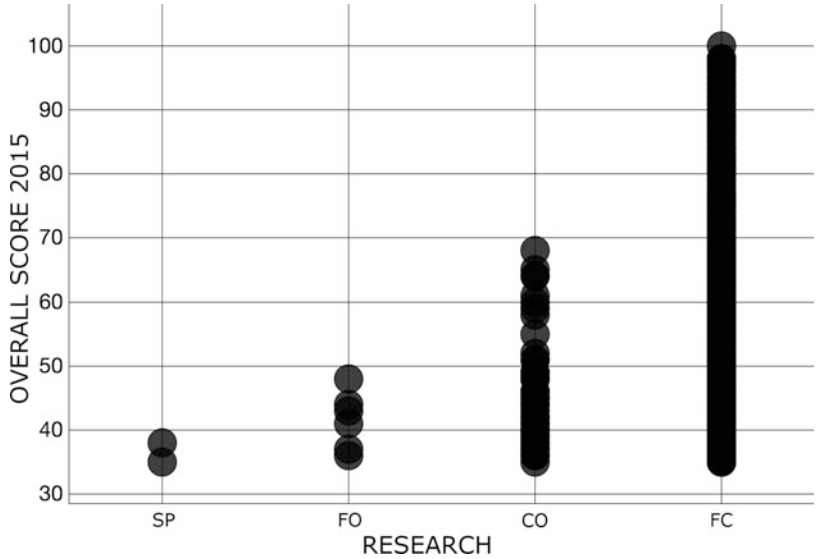
This task refers to the action of inferring knowledge from the visualized information, such as defining hypotheses, rules, probabilities or trends, attributes of cause and effect. This task usually takes place after determining, identifying, or comparing information, and it is performed as part of the mechanism of data analysis, thus it may not be completed at once, requiring consecutive applications of the other visualization tasks. By analyzing Fig. 1, it is possible to infer a hypothesis, e.g., that the y variable is the cause of the trend of the data.

Locate

This task refers to the actions of searching and finding information in the graphic representation: they can be data points, values, distances, clusters,



Multivariate Visualization Using Scatterplots, Fig. 3 A scatterplot visualization that simplify the computation of the mean



Multivariate Visualization Using Scatterplots, Fig. 4 A scatterplot configuration that enhances comparison

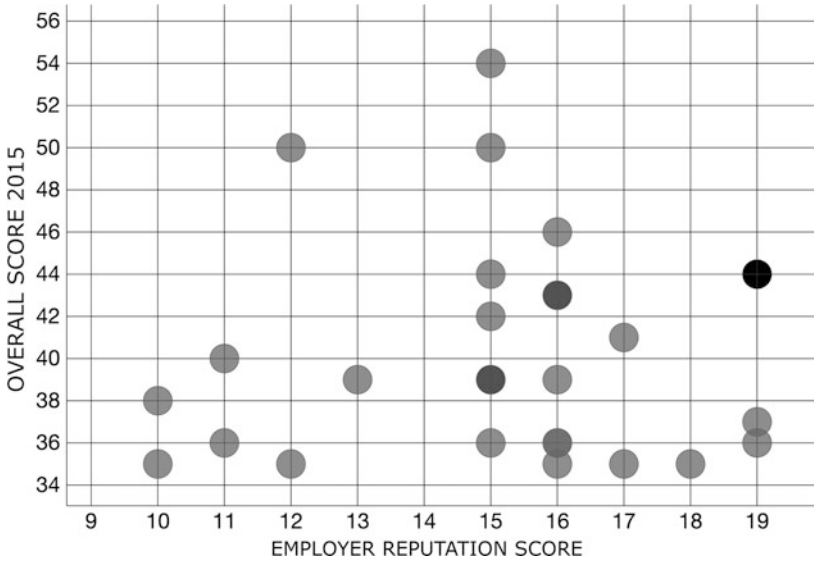
properties, or other visual characteristics. The task begins when the user starts examining the visual representation and finishes when he/she recognizes the desired information. Figure 5 shows a scatterplot visualization that enhances the identification of outliers.

Dimensions

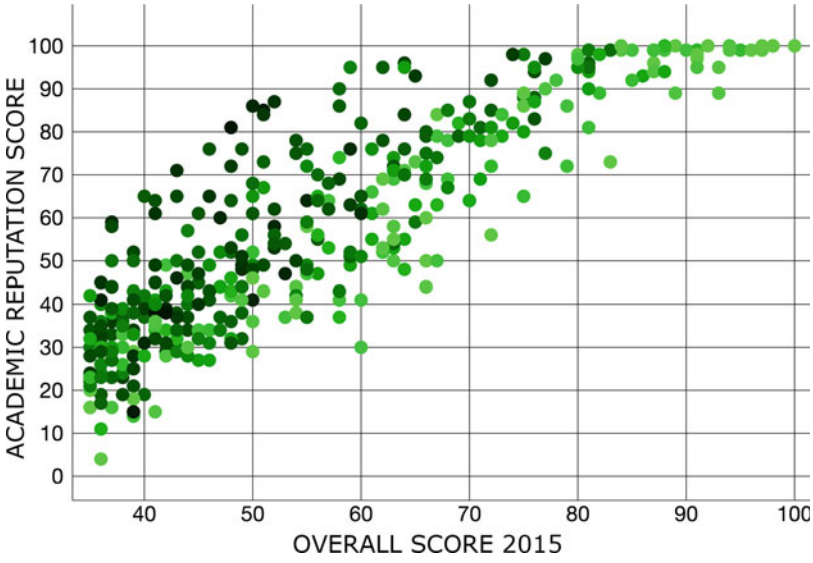
The main problem when using the scatterplot to visualize multivariate data is that its basic version is limited to only two variables, thus making it difficult to correctly visualize and analyze all the data. In order to overcome this problem, different solutions have been proposed through the years to enhance the scatterplot.

Adding Dimensions

Even if the basic scatterplot may display only two variables, various techniques have been researched and adopted through the decades to increase the dimensionality of scatterplots by one, two, or even several additional dimensions. A bidimensional planar scatterplot of two variables X and Y can display additional variables



Multivariate Visualization Using Scatterplots, Fig. 5 A scatterplot visualization that enhances the identification of outliers



Multivariate Visualization Using Scatterplots, Fig. 6 A scatterplot with an additional variable visualized as color

by correlating them to one or more graphical features of the plotted points.

Color

One approach is to show a third dimension through a color map. Colored points on a scatterplot may suggest similarity among values of the same dataset or correspondence among points of different datasets. Moreover, this correlation may be perceived without drawing any connecting line. This technique is particularly powerful since it could also be used to link together an arbitrary number of scatterplots, both different or complementary, such as in the case of a scatterplot matrix, without cluttering or visibly degrading any of them. This solution can increase significantly the effectiveness of such visualization with respect to the sum of the individual unlinked scatterplots. Colors can also be used to enhance the perception of a variable already displayed by another effect (such as an axis). Figure 6 shows a scatterplot that displays an additional variable through colors.

Size

A further option to provide an additional dimension to the scatterplot is to vary the size of the points. Anyway, this option may lead to occlusion problems if the plot does not provide proper scaling on the two axis. Figure 7 shows a scatterplot with a variable mapped on the size of the points.

Shape

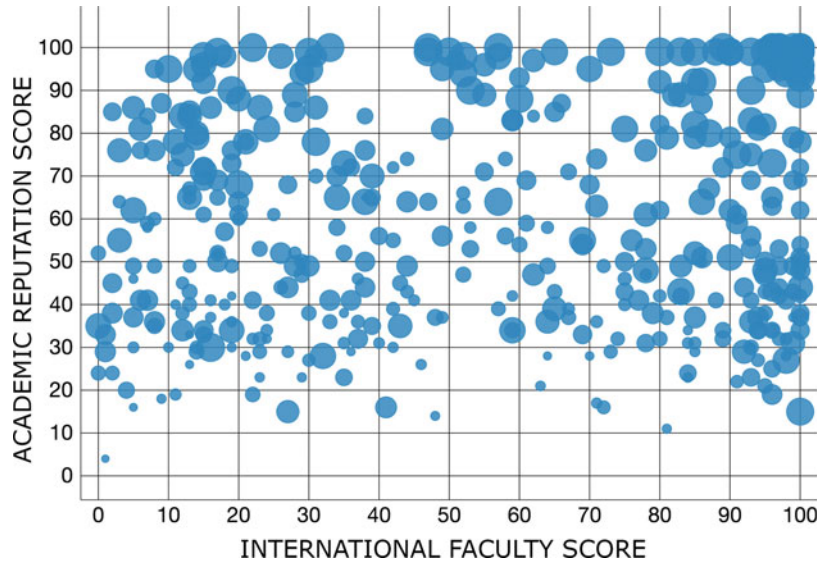
Another approach is to add a third dimension changing the shape of the points. Instead of using only points, each element of the dataset could be drawn as different kinds of glyphs depending on a third variable. This option leads to further possibilities in terms of the paradigm used to choose the shape. One option is to display the points as "flowers," relating the variable to the number of "petals" to display. Another option is to display polygons and relating the number of sides to the variable. Moreover, various glyphs, clearly distinct among them, could be used to represent different datasets. Figure 8 shows a scatterplot that uses the shape of the points to display additional information.

Orientation

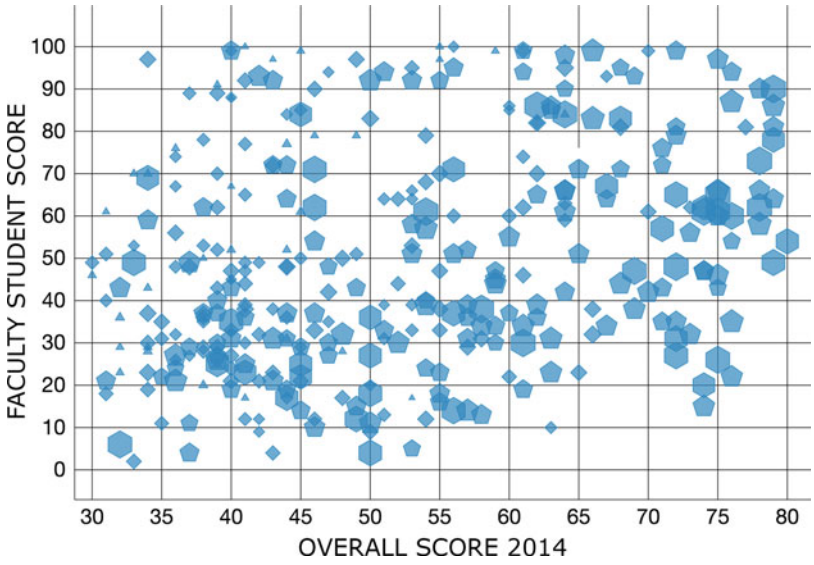
Another possibility when displaying points as shapes is to represent a third dimension changing the orientation of the shape. Usually, a dot or line is drawn orthogonally to the perimeter of the shape to better identify the reference point for the orientation. Figure 9 shows a scatterplot that displays an additional variable through the orientation of the points.

Error Bars

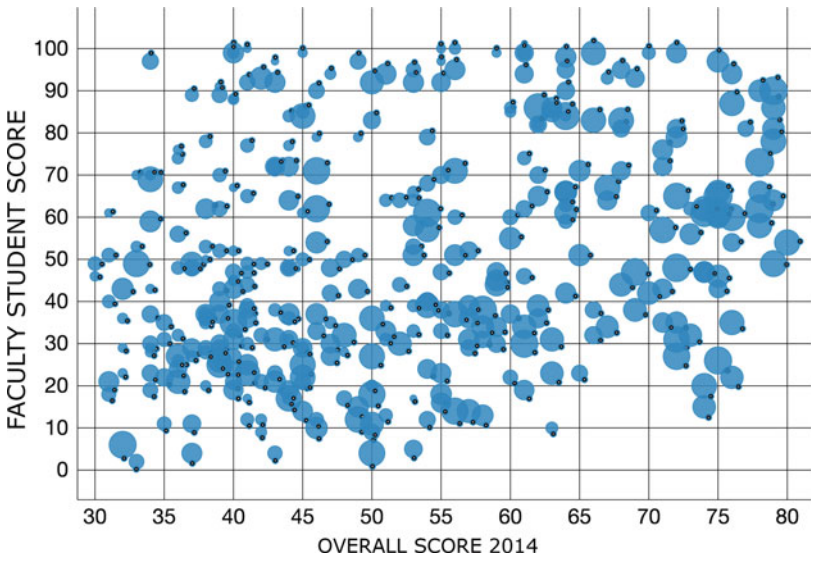
The uncertainty is the variability related to a specific variable of the dataset for each point. It provides a generic idea of how precise the measurement of the reported value is or how far from the recorded value the real value might be. This information is usually reported through error bars if it is related to a variable mapped on the x or y axis (or both). Figure 10 shows three examples of error bars. Error bars require additional space around the points to be correctly displayed due to the chance of overlapping between points. For this reason, they are usually adopted only if the points of the scatterplots are very scattered and occlusions do not occur. Otherwise, the use of error bars would greatly affect the understandability of the representation. As a result, the use of error bars limits the number of different graphical effects that could be combined on the same scatterplot and should be avoided when displaying more than three or four variables.



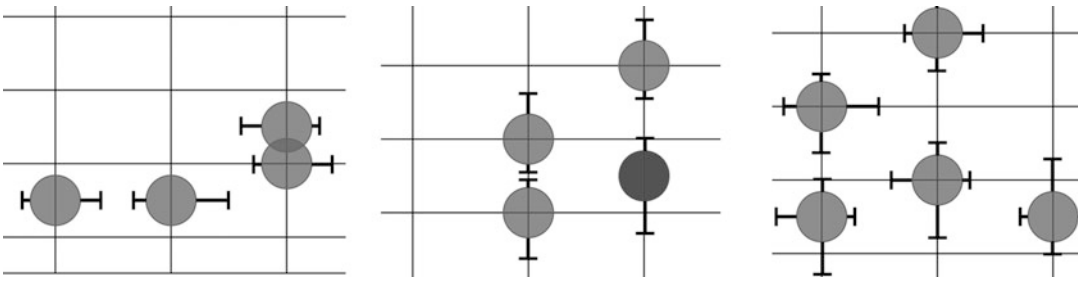
Multivariate Visualization Using Scatterplots, Fig. 7 A scatterplot with a variable mapped on the size of the points



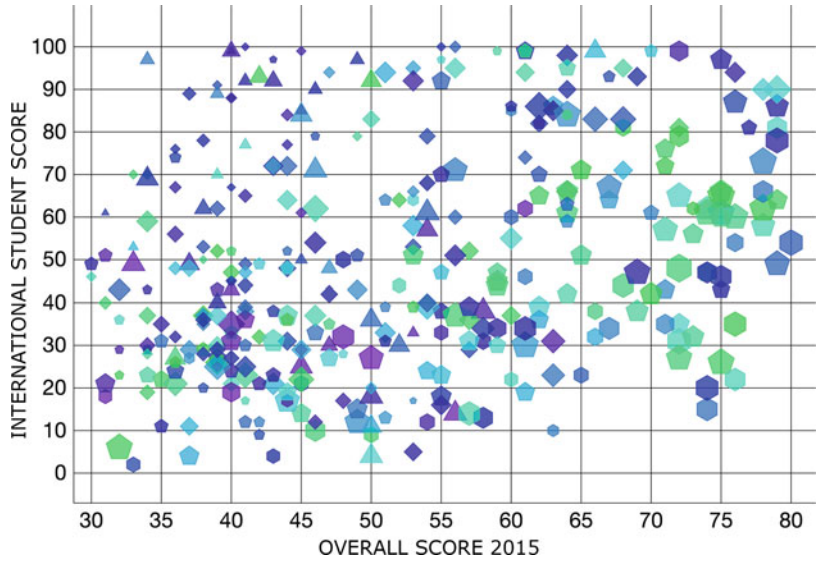
Multivariate Visualization Using Scatterplots, Fig. 8 A scatterplot that uses the shape of the points to display additional information



Multivariate Visualization Using Scatterplots, Fig. 9 A scatterplot that displays an additional variable through orientation



Multivariate Visualization Using Scatterplots, Fig. 10 Three examples of error bars



Multivariate Visualization Using Scatterplots, Fig. 11 A scatterplot that displays multiple variables through different effects

Adding More Dimensions Concurrently

It is possible to use simultaneously more than one of these techniques, independently, to obtain even high visual dimensionality. Figure 11 shows an example of such a scatterplot. However, this is recommended only if the graphical effects are clearly distinguishable, otherwise the visual clarity and benefits of displaying more dimensions at the same time will promptly worsen. Many studies, like the one by (Demiralp et al. 2014), have been carried out to understand how visualization design can benefit from taking into consideration perception, as different assignments of visual encoding variables such as color, shape, and size could strongly affect how viewers understand data.

Dynamic Visualizations

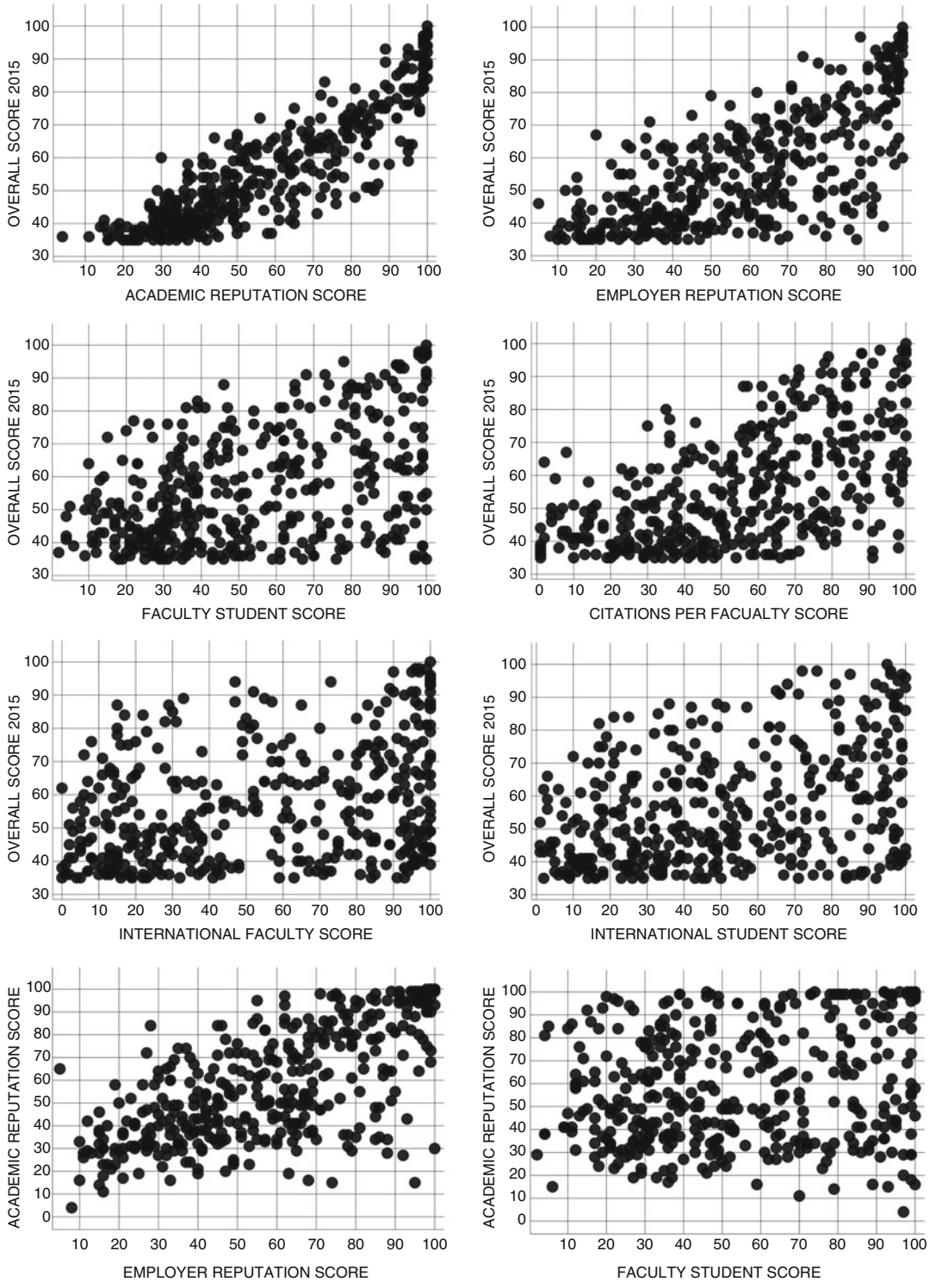
Even if scatterplots are typically used to display static data, nevertheless they can be very useful when applied to display data that could change dynamically, moreover if the change may be controlled by the user. More complex graphical effects such as animation may be adopted in this case to enhance the comprehension of data as they change over time. This is the case of data characterized by one or more time-related variables, such as stocks values in finance or weather conditions in forecasting.

Scatterplot Matrix

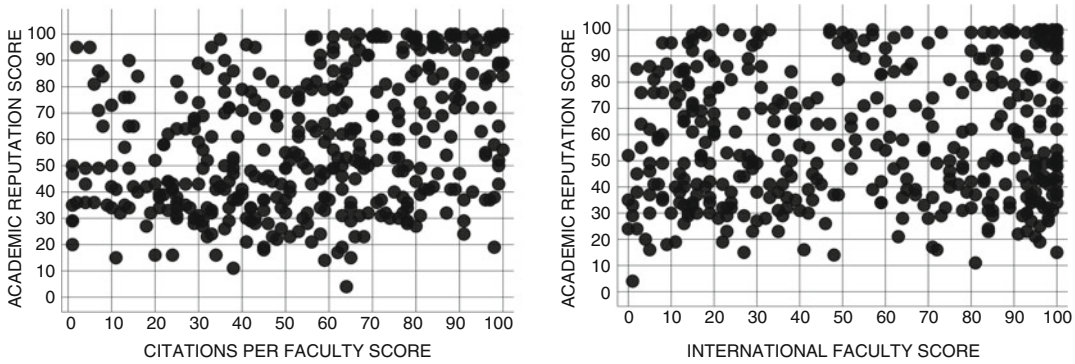
The simplest approach to adapt the scatterplot to multivariate data is to produce a series of scatterplots for each pair of variables and display them together on a single screen or page. This visualization technique is called scatterplot matrix and for k variables it requires k(k-1)/2 pairs and therefore scatterplots. Unfortunately, this solution presents a major problem: analyzing all the scatterplots may require a lot of time, depending on the number of variables, thus this solution is not optimal when dealing with time-related tasks. To overcome this problem, different visualization techniques may be adopted to interact with the dataset and simplify data comprehension. Figure 12 shows an example of scatterplot matrix.

Brushing

Brushing is the action of selecting a subset of the points displayed on the scatterplot. Four brushing operations have been defined by Becker and Cleveland (1987): highlight, shadow highlight, delete, and label. To perform these operations, it is necessary to resize a rectangle, called the brush, over one of the scatterplots. The corresponding points on each different scatterplot are then affected by the chosen operation. The brush can be moved to different regions of the scatterplot by



Multivariate Visualization Using Scatterplots, Fig. 12 An example of scatterplot matrix



Multivariate Visualization Using Scatterplots, Fig. 12 (continued)

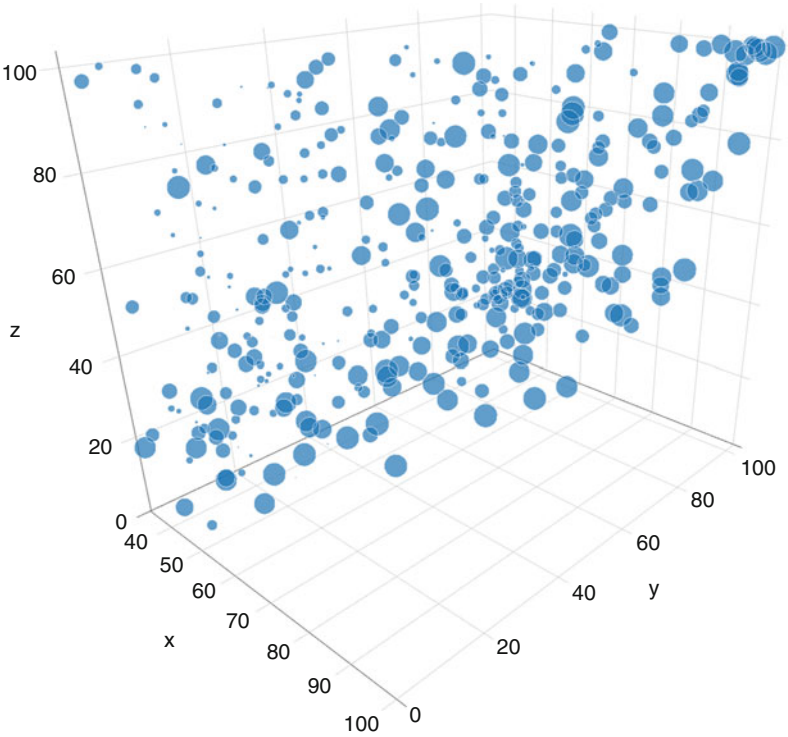
moving the mouse. At any time, the user can stop the brushing operation, change the shape of the brush or the chosen operation, and then resume the brushing.

Dimension Reordering

One of the problems when dealing with scatterplot matrixes is to simplify the understandability of the data. One possibility is to change the way the scatterplots are displayed and ordered to enhance the presence of clusters, patterns, or trends. Different approaches have been investigated and adopted, such as the systematic dimension reordering approach of Ankerst et al. (1998) where similar dimensions in a multidimensional dataset are placed next to each other. Using a scatterplot matrix it is possible to order independently rows and columns. In the systematic dimension reordering approach, similarities are displayed on the column and dissimilarities on the row order.

3D Scatterplots

Another way to display multidimensional data through scatterplots consists in adopting a 3D visualization. 3D scatterplots exploit the third dimension, representing three data dimensions on the x, y, and z coordinates, in a three-dimensional space. The third dimension allows the user to interact with the scatterplot to change the viewport (with two or three degrees of freedom). Hypothetically, more coordinates could be added to the model, leading to an n-dimensional spatial representation. Since 3D scatterplots are represented on displays as 2D images, the 3D representation needs to provide useful hints to properly display depth and avoid occlusions or misinterpretations of data. Occlusions can be addressed also in 2D representations by using another data dimension for depth sorting. The latter can also be compared to a full 3D scatterplot where the only difference is the missing rotational interaction in 3D. This mapping also requires three axis: two for spatial positions and one for sorting. 3D scatterplots make it possible to obtain more flexibility in the data mapping simply avoiding to fix certain data dimensions to only certain specific scatterplot axis: this could be obtained allowing the user to exchange the dimensions mapped on each axis, either by swapping the dimension of one or two axis or by manipulation of dimensions. 3D scatterplots may also consist of more complex versions, including additional graphical effects (color, size, orientation, shape, etc.) to represent additional information related to the displayed data, guideways (reference lines from the data up to some reference points) and combinations of scatter data with additional objects as fit surfaces. A common application of the 3D scatterplot is to show both experimental and theoretically adjusted data in order to be able to determine the points of agreement. In Fig. 13, a scatterplot can be observed in three dimensions that makes use of the size of the spheres to map an



Multivariate Visualization Using Scatterplots, Fig. 13 A 3D scatterplot displaying an additional variable through size

additional attribute. Overall, 3D scatterplots have certain advantages and limitations with respect to 2D models, as depicted by Escudero et al. (2007).

Advantages

In a 3D scatterplot, maintaining the same density of points as in a 2D scatterplot involves increasing the number of experimental data to be displayed (larger sample space). If the number of points of the initial 2D scatterplot is maintained, there is a greater discrimination of the relations between variables, since a characteristic is added to the data. The use of volume visualization in 3D scatterplots provides the possibility of generating glyphs by procedural techniques: the form of the glyphs is computed by a mathematical formula which determines the number of lines or sides (Ebert et al. 2000). These techniques allow the user to increase the number of dimensions of the data to be shown by exploiting the shape of the glyphs, thus taking advantage of the preattentive ability of the human visual system to discriminate forms. To obtain the best result from a 3D scatterplot, it is necessary to achieve an efficient attribute mapping and to provide the necessary interaction tools to navigate and examine the data: these requirements enhance the expressive power of a 3D scatterplot and allow the user to analyze complex relationships among multiple variables.

Limitations

It is not advisable to abuse multidimensionality if it is not absolutely necessary and the result is not visually illustrative. Moving information representations from 2D to 3D is not a simple task, since the extra dimension may greatly affect how information can be presented and interpreted. The visualization must make an efficient use of the additional dimension and avoid that the new representation is misinterpreted by the user as a consequence of an inappropriate mapping. Special consideration must be given to the perception of spatial distance. The size of the objects can cause the user to not perceive the correct perspective of the information shown: it is difficult to discriminate among the different depths of the objects, and to address this problem it is necessary to provide

the appropriate interaction tools. A disadvantage arising from the use of three-dimensional objects is occlusion, which occurs when one object covers another or occupies the same spatial position for two coordinates in the 3D representation. This type of problem occurs mainly when the density of data items to be displayed is large or when simply a very large object is positioned in front of smaller objects.

Remarks

The reason behind such a various enumeration of scatterplot solutions is that none of them could be considered the best version: each implementation could be less or more useful depending on the specific task the user intends to solve. Eventually, more than one kind of scatterplot should be used for the same dataset to address different tasks. Overall, a simple classification could distinguish among 3D scatterplots, scatterplot matrices, and standard scatterplots with additional dimensions. 3D scatterplots are more useful when dealing with a huge amount of data with a dense distribution on the x and y axis, allowing the user a better analysis through spatial navigation. Scatterplot matrices are more useful when the task is to search for correlations between two variables of the dataset: each scatterplot of the matrix may display two variables, and the user just need to analyze them all, one by one. For other tasks, the best solution is adding dimensions to the standard scatterplot, as different graphical effects provide a better insight on the data depending on visual perception criteria, as investigated by Demiralph et al. (2014) and many others.

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Multiverse

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MVC Design Pattern

► Interactive Computer Graphics and Model-View-Controller Architecture

N

Narrative

► Game Writer's Dilemma: Context vs. Story
► Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation

Narrative Design

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Synonyms

Allegory; Digital storytelling; Interactive narratives; Interactive storytelling; Semiotics of computer games

Definition

Narrative design combines game design and game writing. It uses the mechanics of game design to create a dramatically compelling story to the game player. In a broader sense, narrative design is a unity of carefully selected game mechanics that would adhere the story elements in either textual or symbolic/visual form with the aim to fulfil the desired gaming experience for the players. Narrative design can be textual, visual, or aural. It is usually a tight bond of all these mediums telling the story directly through players' senses in a form of gaming experience that was set by the game designer.

Introduction

A narrative designer works together with the rest of the game development team from the conception to the release of the game (Heussner et al. 2015). The collaboration is closest with the game designer, who is responsible for the vision and idea of the whole game. The narrative designer focuses on bringing in and integrating the story so that it seamlessly fits into the game design and complies with the game mechanics and art style. Narrative design requires a special set of skills, and many writers coming from more traditional media might find it difficult to give up authorial control and to adapt to work within the confines of the game system and as a part of a multidisciplinary development team. Furthermore, the narrative designer commonly directs the graphics and audio team in creating the right environment, character design aesthetics, and all other visual elements that would highlight the story content for more immersive gaming experience.

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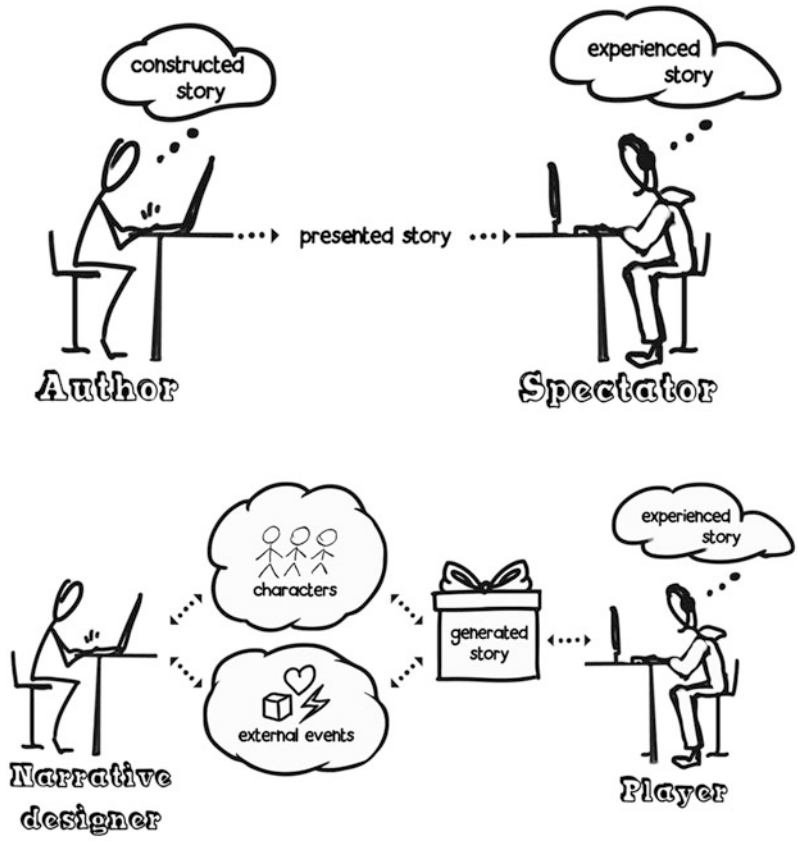


Narrative Design, Fig. 1 In traditional storytelling, once the author has created the story, it is presented the same way to all spectators. In interactive storytelling, the narrative designer is responsible for the characters and events in the storyworld, which are used to generate the story in line with the player's individual preferences and expectations

What sets narrative design apart from traditional storytelling is the player's influence on the story being told. This creates a friction that the narrative design has to solve. There are different approaches on how to handle this depending on how much narrative control is given to the player. The narrative designer can employ different methods for guiding the player to make impact on the story progression, which we will present later in this article.

Academic research on digital storytelling has a long history (Koenitz et al. 2015), but from 1990s onwards it has focused especially in interactive narratives. Seminal works in this field include books by Laurel (1991, 2014) and Murray (1997, 2017) and the proceedings of the International Conference on Interactive Digital Storytelling (http://icids.org/). One of the key problems tackled by the research is the role of the player's narrative agency with respect to the author's control over the story, which we will discuss next.

Narrative Control Versus Narrative Freedom

Interactivity is the key difference between games and other forms of media, and game technology provides a new medium of expression where an essential part of experiencing the story happens through a direct participation with the narrative progression. In traditional storytelling, the flow of the story is linear with clear stream from the author to the audience. In interactive storytelling, the audience has an active part in shaping up the story and co-creating it with the author (see Fig. 1). Outside of the digital realm, this kind of storytelling happens, for example, in improvisation theater and (live action) role-playing games. Also, teaching and tour guiding are such endeavors where the audience participation – ideally – has a significant effect on the outcome of the story. This also opens the topic of diversity in experiencing the

narrative within a solitary gameplay or as a part of a group effort.

Interactivity allows the player to have *agency* in the story, which means that the player can make meaningful choices affecting the story's direction. This requires that the game conveys information on the possibility of a choice to the player. Moreover, the player must, at the time of making the choice, have an idea on the possible consequences of that decision. Finally, to have agency, the ramifications of the choice in the story must be seen immediately and – to maximize the effect – they should also show an effect at the end of the game.

The requirement of narrative agency – or freedom of choice – contradicts with the idea of a story being authored. The player can refuse to follow the intended story and do something else instead. For example, imagine a game based on the film *Star Wars: A New Hope*. Now, the player controlling the character of Luke Skywalker could refuse to leave Tatooine preferring to lead a life of a farmer. How could the author persuade the player to follow the intended story and leave the planet with Obi-Wan Kenobi and the droids?

One possible answer is to increase the limits of the freedom of choice and forcing the player into a certain direction – either by hinting or even by coercion. This resembles the situation in the film *Stranger Than Fiction*, where the main character is hearing a voiceover of his life. At some point, he decides not to follow it and instead goes back to his apartment only to discover how hints (e.g., mail, news program, commercials) turn into coercion (wall being bulldozed down) forcing him eventually to follow the voiceover's story (this same conceit is also used in the game *The Stanley Parable*).

This problem is called the *narrative paradox*, and there are different proposals on how to solve it. One possibility is to take a high-level approach that posits that the player enters into a contract with the author meaning that the player will obey the constraints of the storyworld (Adams 2013). The same happens in games in general: the game designer is the one setting up the moral of the game world (i.e., which actions are "good" and which "bad"). For example, a pacifist stance is not "good" in the moral system of a first-person shooter game, because it makes impossible proceed in the game.

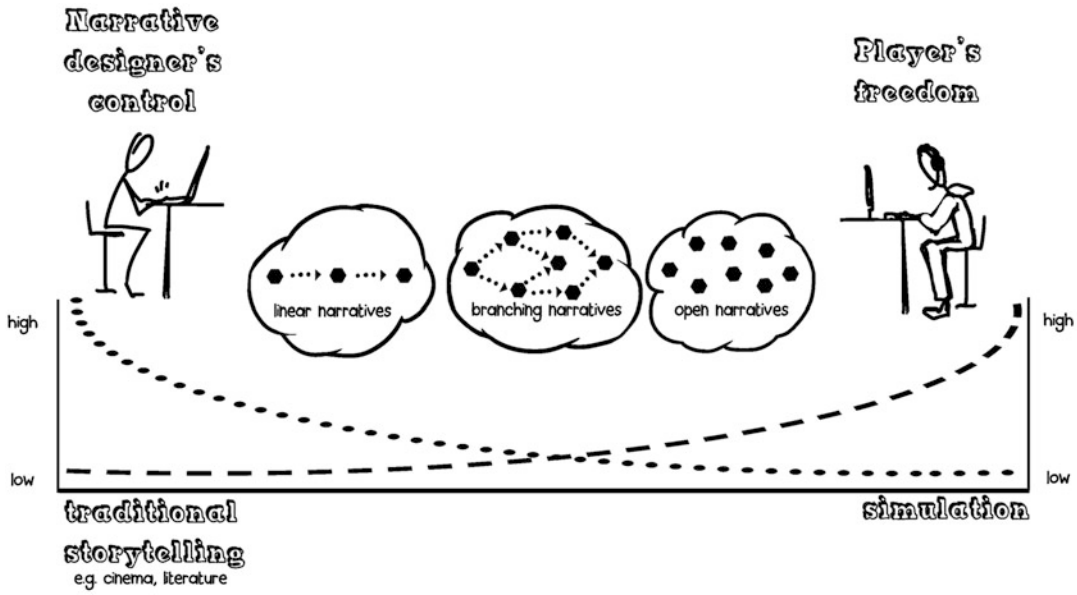
A design-oriented solution to the narrative paradox has two opposite approaches (Smed 2014). Author-centric approach puts the author's control in the first place. This leads to having a part of the software, a *drama manager*, which acts as a proxy for the author and tries to manipulate the game world and its entities so that the player follows the intended route lined out by the author. Naturally, this can lead to a situation called "railroading" where the players – regardless of their skills and abilities – are at the mercy of the game story.

Conversely, the character-centric approach sees the author as a Newtonian god, setting up the game world and its entities and leaving them alone to interact once the game starts. This so-called *emergent narrative* depends highly on the underlying simulations, especially the computer-controlled characters, but gives no guarantee whether a story comes up from this process. Naturally, this can be enhanced by reintroducing the drama manager as a behind-the-scenes partaker, which the characters can consult for making dramatically compelling decisions, leading to a hybrid approach.

Designs for Interactive Narrative

Figure 2 illustrates the continuum of narrative types used in games. As the narrative paradox indicates, the narrative designer's control over the story and player's narrative freedom exclude one another: the higher the narrative designer's control, the less narrative freedom the player has, and, conversely, high narrative freedom of choice means reduced control for the narrative designer. At one extreme, we have the case where there is no freedom, which constitutes a reduction back to traditional linear storytelling (e.g., cinema, literature). At the other extreme, we have no authorial control of the narrative, and the game is reduced to just a simulation.

Between the extremes we have three different approaches to incorporate narrative into games (Heussner et al. 2015; Zeman 2017). The most widely used is *linear narratives*, where the story



Narrative Design, Fig. 2 The spectrum of narrative types in games

progresses linearly (e.g., through cutscenes between the levels or environmental changes) but the player has freedom in the gameplay. This means that every player will every time encounter the same story in the same order. Although the player, therefore, lacks narrative agency, the story can be woven into the level design such a way that the player's actions seem to have an influence in the story as well. For example, the killing of a level boss can be followed by a cutscene, where the allies of the boss get involved in the conflict. Although the killing of the boss was necessary for the player to proceed in the gameplay, now it seems to have repercussions in the story as well. This pseudo-agency provides the players with a feeling that they can affect also the story.

Ideally, each narrative choice would lead to a new and different situation meaning that the player could try out all possible scenarios like in the film *Groundhog Day*. However, this full branching leads to a combinatorial explosion, where the shear amount of narrative alternatives becomes infeasible to handle. In practice, these kinds of *branching narratives* use pinch points, where the divergent paths join reducing the number of alternatives. An early and nondigital example of this approach is the *Create Your Own Adventure* book series, where the reader has to choose at the end of a chapter how the story continues and then skip to the indicated page to continue reading. A classic example of a game using branching narrative is *Indiana Jones and the Fate of Atlantis*, where the story early on branches to three alternative paths – team, wits, or fists – and later on a pinch point brings all three paths back together.

In branching narratives, a key question is the critical path, which connects the start to the end of the narrative. Maintaining the critical path is an important task for the narrative designer so that the story progresses no matter what the player chooses. To enlarge the storyworld the designer can add short linear narratives that are separate from the critical path and optional to the player. They can be individual quests or tasks that the player can take, which can expand the overall fabula of the game.

Open narratives present the biggest challenge to the narrative designer. Here, there is no imposed sequence for the narrative events but each player can take their unique path. These

kinds of sandbox games can include preconditions for the narrative elements, which provide some structure. For example, the game *Her Story* has a complete but deconstructed underlying story, which can be experienced in any order by entering keywords to the game's internal search engine. However, the players are most likely to search terms related to events happened recently, hence creating a loose structure into the open narrative.

Another possibility to create a structure into the openness is to scatter the story throughout the levels (i.e., each level has its own set of open narratives). Also, some story elements can be threaded so that they form short linear sequences. These (possibly optional) threads can include missions, quests, jobs, or rescues taken inside of a larger context.

The Form of Storytelling

Although narrative design is often thought as textual, it can also include visual or aural elements – or even omit the textual narrative and focus on other forms of conveying the story. Let us look and compare how some games present a complex narrative design to a player using different forms of storytelling. A common feature to these games is they have a deep narrative design with a main protagonist that reflects to the players' preferences in a gameplay – the player can decide the course of the narrative from aggressive/achievement-driven to more adventurous/story-driven experience.

To provide an open world experience with a feel of free exploration in *Horizon Zero Dawn,* the narrative designer and the game designer have used a variety of traditional methods of literary and rhetorical allegory in revealing the story. Conversely, in games such as *ABZÜ* or *Journey*, the creators have focused fully on the visual storytelling methods with an almost complete absence of textual content in the game. In such an approach, semiotics theory (Schapiro 1969) and iconography (Panofsky 2003) have an essential role in creating the interactive narrative experience for the players, where even the symbolism of a color or the type of light and the texture in a scene can provide necessary information for the player to progress in the game. Naturally, this makes high demands on the graphics team, since their task is to translate the narrative design into a visual narrative by using all possible tools from semiotics, psychology, and symbolism theories. Moreover, this visual translation of the story-driven experience needs to be easily understood via a seemingly simple user interface design and clear indicators in the game environment that guide the player in the story progression.

The game *Life is Strange* is based on more traditional storytelling methods, where the player makes clear choices from a given branching narrative. The story progresses as an episodic interactive narrative, which is also common in visual novels and interactive fiction. In these games, narrative designers focus on specific segments of the story that give a full loop and a sense of conclusion by the end of the game, and, at the same time, the story has enough of open-endedness that it can continue in another episode as a sequel, or even completely new game-titles that refer to the previously given narrative experience. Still, the follow-up game can usually be played and experienced without having played the previous game in the series, which is the case in adventure games such as *Zelda*, *Tomb Raider,* or *Assassin's Creed*. The storyline binds all the games – and the big narrative construction that represents the game world and all its content – under one title. The introduction and tutorial parts of a game serve as an "onboarding" to the given narrative framework for the players not already familiar to the preceding games in the series.

Conclusion

Narrative design takes the challenge of combining stories and games. This requires an understanding of the needs of interactivity and narratives. The end result should be a game that is dramatically compelling without hindering the player's agency

too much. To realize this, the narrative designer has three broad approaches – linear narratives, branching narratives, and open narratives – to choose from and can then refine it to fit in with the gameplay and the story being told. Contemporary game design tendencies highlight the importance of an individual gameplay experience that accommodates to the player's personal preferences. Therefore, the player is provided with necessary tools to shape the narrative progression according to their own individual expectations and desired game experience.

Every game – no matter how simple or complex its structure may seem – has a goal for the player to achieve. Narrative design is where the game mechanics, visual and aural content come together to give the feeling of a purposeful experience in pursuing that goal.

Cross-References

- ▶ Game Design
- ▶ Game Writer's Dilemma: Context vs. Story
- ▶ Game Writing
- ▶ Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation

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Narrative in Video Games

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Synonyms

Ludonarrative; Video game narrative

Definition

Today, no generally accepted definition of video game narrative exists. The academic discourse has pointed out ontological and phenomenological differences to more traditional forms of narrative, and therefore, the relationship to established scholarship in narratology is complex. In the field of video game studies, narrative aspects of video games are often described in contrast to rule-based aspects. A wider scan of related fields reveals additional positions. Ludonarrative is variously understood as a structural quality of the video game artifact, as an experiential quality during the experience of a video game, or as a high-level framework to understand video games. Finally, a number of scholars emphasize the difference to traditional manifestations and therefore work towards specific theories of video game narrative. While all legitimate by themselves, these different usages of "narrative" in the context of video games are often not clearly distinguished in professional or academic discourse and can lead to considerable confusion. It is therefore essential to scrutinize the particular context and underlying assumptions when approaching the topic. This state of affairs puts particular responsibility on scholars to identify

the origins of their understanding of video game narrative and define their particular usage of the term in contrast to earlier applications.

Introduction

Video game narrative has been the topic of much scholarly and professional debate (see "Narratology vs. Ludology debate" below). Both academics and practitioners are divided on the potential and scope of narrative in regards to video games. A foundational issue of these perspectives is the lack of a shared understanding of "narrative" – the term might be variously used to mean an ornamental function to provide context (Juul 2005), a structural quality of the video game artifact (Fullerton et al. 2008), an experiential quality during the experience of a video game (Pearce 2004; Salen and Zimmerman 2004), or a high-level analytical framework to understand video games (via textual analysis (Fernández-Vara 2014)). Each of these perspectives represent valid approaches; however, implicit definitions of "narrative" are prevalent in academic and professional discourse on video game narrative, and thus the particular meaning used is often not readily accessible. The topic therefore needs to be approached with particular scrutiny to carefully unpack the underlying assumptions of a given academic paper, professional publication, or audience reaction. In other words, one scholar's "experience dimension" might be another scholar's "narrative" and one developer's "level design" might be an audience member's "narrative." As a generally accepted definition of "narrative" (and the related term "story") seems elusive for the time being, scholars and professionals working on video game narrative are highly encouraged to make their respective definitions and underlying assumptions explicit.

Analytical Perspectives: Understanding Video Game Narrative

Early Perspectives

Early scholarship on video games understands narrative as a natural ingredient, for example, the first PhD thesis on the topic in 1985 by M.A. Buckels analyses the first text adventure as a "Storygame": Interactive Fiction: The Computer Storygame "*Adventure*" (Buckles 1985). Later publications by Brenda Laurel (Laurel 1991; Laurel 1986) also center on narrative. Theorists of Hypertext literature such as Jay Bolter (Bolter 1991) and George Landow (Landow 1992), intent on using computers as means to implement post-structuralist ideas of narrative, developed analytical frameworks and introduced sophisticated concepts like that of variable "contours" (Bernstein et al. 1992) – narrative forms that enable their own reshaping. It was however Janet Murray's seminal book *Hamlet on the Holodeck. The Future of Narrative in Cyberspace* (Murray 1997) that alerted a wider audience of the narrative potential of the digital medium. The essence of Murray's book is not in the vision of the holodeck itself (a frequent misunderstanding), but instead in the development of two sets of related and influential analytical categories for interactive forms of narration: the affordances (participatory, procedural, spatial, and encyclopedic) and aesthetic qualities (immersion, agency, transformation) (cf. (Harrell and Zhu 2009; Mason 2013; Tanenbaum and Tanenbaum 2015; Wardrip-Fruin et al. 2009) for further developments of these categories and (Roth and Koenitz 2016) for an application in user experience research).

The "Narratology Vs. Ludology" Debate

This academic debate is foundational for the field of games studies and one of its main underlying assumptions, that of a dichotomy between dynamic, rule-based games and static, immutable narratives. This perspective featured prominently in the inaugural issue of the journal *Games Studies* (gamesstudies.org) (Aarseth 2001; Eskelinen 2001; Juul 2001). The debate encapsulates two separate topics, the question of video games as a medium for narrative and the applicability of analytical methods from the field of narratology to computer games. It started in 1999 when Jesper Juul proclaimed: "The computer game is simply not a narrative medium" (Juul 1999), a position Juul later modified (Juul 2001); in the same year, Gonzala Frasca emphasized the need for

ludology in contrast to narratological analysis. Furthermore, he proposed the term "ludology" to mean the "discipline that studies game and play activities"(Frasca 1999). Frasca later defined games as "simulations" with distinct rhetorical possibilities in contrast to narratives (Frasca 2003a) (cf. Bogost's (2007) further development of this perspective).

The pioneering ludology scholars in particular directed their criticism against Janet Murray and Henry Jenkins. In Murray's case, it was her analysis of *Tetris* as a narrative (of an overwhelming onslaught of tasks in contemporary society) in *Hamlet on the Holodeck* (Murray 1997) that provided a particular target for their critique, and in the case of Henry Jenkins it was his understanding of transmedia narratives and of video game design as "narrative architecture" (Jenkins 2004). In that paper, Jenkins identifies a number of productive avenues for game narrative: *evocative*, *enacted*, *embedded,* and *emergent* narrative. *Evocative* narratives reference prior work, for example, a Star Wars Game that refers to the movie series. *Enacted* narratives allow the user to act out roles within an existing narrative universe, for example, as a hobbit in a Lord of the Rings game. *Embedded* narratives convey information by means of narratively meaningful objects and encounters within the game space. Finally, Jenkins describes *emergent* narratives in games like *The Sims* that provide players with the tools to construct stories of their own.

The debate continued at conferences and publications and is most visible in the dialogic form of the electronic version of the edited collection *First Person* (Wardrip-Fruin and Harrigan 2004), for example, Eskelinen's response (Eskelinen 2004) to Jenkins (2004) or Aarseth's (2004) response to Murray's article (2004). After 2004, the intensity of the debate decreased considerably and Murray attempted to put an official end to it in a keynote speech at the 2005 DIGRA (Digital Games Research Association) conference (Murray 2005).

However, the underlying issues cannot be considered resolved. Neither Murray nor Jenkins have ever made claims to be narrative theorists and are better understood as "narrative expansionists" with a purpose to expand our understanding of narrative phenomena (respectively of interactive digital narratives and transmedial narratives). Indeed, Gonzala Frasca's thoughtful contemporary analysis of the debate "Ludologists love stories, too. Notes from a debate that never took place" (Frasca 2003b), rejects the label of narratology for Murray and Jenkins (cf. for actual narratological positions (Ryan 2006; Ryan 2001) or (Neitzel 2014)). Frasca instead issues a challenge to discuss a third, "narrativist" position, which he associates with attempts to create interactive experiences based on literary theory (e.g., Mateas 2001). This interesting perspective of a "third position" has yet to receive sufficient attention, although Eskelinen applies the term later to refer to Murray, Jenkins, and Ryan (Eskelinen 2012). In addition, both the main protagonists (e.g., Aarseth (2012, 2014), Murray in the new edition of *Hamlet on the Holodeck* (Murray 2016)) and additional scholars (e.g., (Calleja 2013, 2015; Ryan 2006; Simons 2007)), continue to reference and discuss the original positions. Eskelinen's recent project of a more universal theory of narrative (Eskelinen 2012) merging narratology (mainly Genette (Genette 1980)) with Aarseth's earlier work on cybertexts (Aarseth 1997) attempts an integration of narrative and games, yet its own persistent distinction between digital and nondigital forms points to the limits of an approach that insists on a media agnostic position (cf. Nausen's warning about "media blindness" (Nausen 2004)). Eskelinen's text so far had limited impact on the ongoing debate.". Conversely, the editor of a recent collection of essays (Kapell 2015) reiterates Frasca's argument that the debate truly never took place and that the questions the debate poses are still unresolved (also see (Mukherjee 2015)).

Therefore, the foundational dichotomy is still influential in video game studies and related fields and by extension in the video game industry, as can been seen in the related term "ludonarrative dissonance" (Hocking 2009) meant to describe a situation of supposed conflict between gameplay and narrative. An example of ludonarrative dissonance would be a character that is portrayed as mild-mannered and considerate in the narrative and yet kills hundreds of virtual characters in the gameplay.

In retrospect, the debate can be seen as productive as far as the development of the study of nonnarrative aspects of games are concerned. However, by entrenching the problematic dichotomy between "game" and "narrative" (maybe most prominently in Juul's book *Half-Real* (Juul 2005)), interest in the understanding of narrative aspects of video games became marginalized in video games studies and consequently, development of specific analytical perspectives has languished. In that sense (and in a somewhat ironic twist) the rejection of narratology has created an analytical void that has more recently been filled by perspectives based in classical (e.g., textual analysis (Fernández-Vara 2014)) and postclassical narrative theory (e.g., Ensslin 2014). One issue with applications of literary-based theory – for example, the reframing of *fabula* and *syuzhet* in a recent paper by Wood (2017) – is that it applies (in this case) structuralist narratology to video games without properly scrutinizing the respective underlying assumptions. This is exactly the danger Aarseth has been warning about: "Do theoretical concepts such as "story," "fiction," "character," "narration," or "rhetoric" remain meaningful when transposed to a new field, [or are they] blinding us to the empirical differences and effectively puncturing our chances of producing theoretical innovation?" (Aarseth 2012). Similarly, Timothy J. Welsh wonders about the influence of established frameworks and asks in a review of Ensslin's book, whether video game narrative has "'matured', as Ensslin suggests, on its own terms," or rather started to produced artifacts that "sufficiently resemble already established artistic practices and critical traditions" (Welsh 2015).

Dissenting Voices

During the main debate Marie-Laure Ryan argues against the rejection of narrative analysis: "The inability of literary narratology to account for the experience of games does not mean that we should throw away the concept of narrative in ludology" (Ryan 2001). She instead proposes to create a new narrative modality for games, in addition to mimetic (enacted) and diegetic (described).

In 2007, Jan Simons offers a pronounced critique of the ludological position: "[. . .] their arguments against narrative and narratology have often been unnecessarily unconvincing." Simons deems the ludologists' arguments "ideologically motivated rather than theoretically grounded" (Simons 2007). In particular, this scholar rejects the distinction between narrative and rules as disproven by emergent narrative in games like *The Sims* series (Wright 2000). Simon's alternative project is in a connection between narrative studies and mathematical game theory (Neumann and Morgenstern 1953). To enable this connection, Simons downplays the importance of the essential category of interaction in video games, of control by the player, and calls it "merely a matter of perspective" already covered in narratology by reader-response theory (Iser 1979). Yet, the kind of cognitive engagement reader-response theory identifies (how readers actively engage with immutable texts in their minds) is not in the same category than the planning and conscious decision-making afforded by video games, where players control the course and outcome (cf. (Koenitz 2010a)). In addition, Simon's focus on outcomes is forced and ignores the fact that games are about experiences, about being "in-game" (cf. (Calleja 2011)). Furthermore, the application of procedural generation to games (e.g., in *No Man's Sky* (Hello Games 2016), a space exploration game in which new planets are procedurally generated) means that some games might no longer have an ending and instead offer infinite gameplay. Yet, even in finite games, players' main focus is not on the ending, but on the experience. To describe a video game from the perspective of the ending means to only incompletely reflect on a 30+ hour commitment and the enjoyment of the in-game experience.

Parallel Developments

Several important contemporary developments in narratology and related fields happened simultaneously with the debate and were not fully reflected in it, most prominently the publication of David Herman's *Story Logic* in 2002. This book marked the "cognitive turn" in narratology, a change from a focus on the analysis of narrative as an aspect of specific forms to an

understanding of narrative as a "forgiving, flexible cognitive frame for constructing, communicating, and reconstructing mentally projected worlds" (Herman 2002) – a flexible definition that can also be applied to video game narrative. Indeed, Marie-Laure Ryan (2006) criticizes the ludologists for basing their critique of narratology on outdated positions (an argument repeated by Calleja (2009)), especially Prince's restricted (and later revised) definition in the first edition of the *Dictionary of Narratology* (Prince 1987) which foregrounded diegetic modes of narrative (the verbal representation of events - "telling") requiring the existence of a narrator, while seemingly rejecting mimetic modes of narrative (the direct presentation of speech and action – "showing"). Ryan therefore rejects the notion of the incompatibility between narratology and ludology and proceeds to locate game narrative with *paidia,* referencing Caillois' (1961) distinction between two kinds of play: *paidia* and *ludus* (essentially free-form and rule-based). This means that computer games which invite make-believe activity – like *The Sims* – can be described as narratives regardless of strong ludic elements. However, Ryan ultimately does not cross fully into the new territory of interactive video game narrative, as she stays convinced that "interactivity is not a feature that facilitates the construction of narrative meaning" (Ryan 2006).

Crossing Ryan's border, other scholars have worked to understand interactive forms of narration and to further develop the analytical arsenal. For the sake of space, the following section can only provide a rough overview of this work and does not claim to be extensive. Additional material can be found for example in the proceedings of the ICIDS (https://link.springer.com/conference/icids) and AIIDE (https://dl.acm.org/results.cfm?query=AIIDE) conferences as well as the INT (http://www.di.unito.it/~rossana/INT10) workshop.

For example, drawing on traditions in semiotics along with poststructuralist and pragmatist narrative theories, Gabriele Ferri (2007a, b, 2013, 2015) develops an "epistemological common ground" (Ferri 2015) to support a multidisciplinary analysis of video game narratives and other forms of interactive digital narratives (IDN). In particular, Ferri tackles the issue of textuality under interactive conditions and provides a model ("interactive matrix") for the encounter of player and computational system.

In 2011, Clara Fernandez-Vara also applies a semiotic perspective – based on Peirce (1992) – to pick up Jenkin's thread of *embedded* narrative (Jenkins 2004) and further develop it as "indexical storytelling" (Fernández-Vara 2011) (in the Peircian sense of indexical signs) through meaningful objects, encounters, and traces left by other players.

In 2001, Michael Mateas develops a poetics for interactive drama (Mateas 2001) extending Brenda Laurel's earlier work (Laurel 1991) in connection to Murray's affordances and aesthetic qualities (Murray 1997) as a theoretical basis for this later narrative artificial intelligence (AI) projects. Mateas' perspective is referenced by Frasca's (2003b), but little further discussion occurred.

Working on narrative in the related field of virtual environments, Ruth Aylett develops a theoretical position on emergent narrative and the problem of the "narrative paradox" (Aylett 2000) (also see the related article on "Narrative Designer's Dilemma" in the cross-references section below) – the conflict between narrative coherence and interactor control. In 2003, Ruth Aylett and Sandy Louchart published a "Narrative Theory of Virtual Reality," which explicitly treats as VR as a narrative medium (Aylett and Louchart 2003). Later, they collaborate on extending narrative theory to cover emergent narrative in AI-based experiences and video games (Louchart and Aylett 2004).

In addition to Aylett, Louchart, and Mateas, a range of additional AI researchers have developed analytical perspectives on narrative alongside their work in applying AI to various forms of IDN (Cavazza et al. 2008; Cavazza and Pizzi 2006; Cavazza and Charles 2002; Riedl 2010; Riedl and Bulitko 2012; Riedl and Young 2006; Bates 1993; Mateas and Stern 2005; McCoy et al. 2009; Saillenfest and Dessalles 2014)).

Design-Based Perspectives

The perspective of game developers towards "narrative" has been described as "pragmatic" (Ryan 2006) in its flexible application of various narrative models and concrete design methods to create video game narrative. The available literature is focused on a traditional understanding of narrative, influenced by cinematic approaches and screenwriting (Field 1979) and prominently features concepts like the "Hero's Journey" (Campbell 1949) (applied for example in Ernest Adams's *Fundamentals of Game Design* (Adams 2010)) or the "story arc." In her book *Game Design Workshop* Tracy Fullerton writes: "[. . .] the tension in a story gets worse before it gets better, resulting in a classic dramatic arc [. . .] This arc is the backbone of all dramatic media, including games" (Fullerton et al. 2008). This traditional understanding of narrative is foregrounded also in an opinionated column in the same book by game designer Jesse Schell, author of another influential book on game design (Schell 2008). In particular, Schell denounces the idea that the interactive aspect of games have a fundamental influence on narrative: "The idea that the mechanics of traditional storytelling, which are innate to the human ability to communicate, are somehow nullified by interactivity is absurd." (Fullerton et al. 2008) A critique of Schell's perspective can start with the realization that his notion of "traditional storytelling" is based on a narrow, colonial perspective of narrative that ignores many non-European varieties (cf. (Madej 2008)) with very different mechanics, for example, multiclimactic, cyclical African oral storytelling forms (Jennings 1996), Asian structures that lack a tension arc (Kishotenketsu) (Koenitz 2016), or forms of participatory theater like Arturo Boal's "Theatre of the Oppressed" (Frasca 2001). Schell's assertion is therefore untenable and points again to the fundamental problem of totalizing and implicit assumptions (in Schell's case that of a universal "mechanic of traditional storytelling") in the discourse about video game narrative.

During the Narratology vs. Ludology debate, Celia Pearce argues for a relocation of narrative in video games as an element of the player experience. She develops a set of categories to describe narrative aspects: *Experiential, Performative, Augmentary, Descriptive, Metastory,* and *Story System* (Pearce 2004). For her, the *Experiential* aspect always exists, while the other ones depend on the specific implementation in a particular artifact. Pearce' foray into the experiential dimension is significant, as she opens up a productive avenue to analyze video game narratives. However, her framework carries the danger of understanding all in-game experience as narrative. Conversely as Calleja reminds us (2013) referencing Aarseth (2004) if everything is narrative, nothing is.

The experiential perspective is also a cornerstone of Salen and Zimmerman's game design book *Rules of Play*. They write: "our intention is not just to arrive at a formal understanding of narrative (What are the elements of a story?) but instead an experiential one (How do the elements of a story engender a meaningful experience?)" (Salen and Zimmerman 2004). For these authors, the main question is how to best design "narrative play" (ibid). A decade later, Teun Dubbelman makes this perspective even more concrete in his analysis of "Narrative game mechanics" (Dubbelman 2016).

Specific Approaches

Instead of defining video game narrative within the framework of traditional narratological analysis and forms, Calleja (2013, 2015) and Koenitz (2015, 2010b) argue for the development of a specific theory of video game narrative (for Koenitz as part of a wider understanding of interactive digital narrative (IDN) phenomena like interactive documentaries, electronic literature, artistic installations). Calleja contends that the lack of progress in understanding video game narrative is due to the overly reliance on "classical notions of narrative developed for non-ergodic media such as film or literature" (Calleja 2013). He therefore calls for a re-conceptualization of narrative that takes into account "the cybernetic nature of games and thus factor in the experiential

dimension of the human as well as the formal properties of the game." (ibid). Conversely, Koenitz references Roy Ascott's theory of cybernetic art (Ascott 1968, 1967, 1964) as a basis for his SPP model (System, Process, Product) (Koenitz 2015, 2010b). The triad of System – Process – Product (digital artifact, user interaction and resulting output) bridges the gap between artifact and instantiated narrative (cf. Montfort (2005)). By understanding the content of the system as a "protostory," the narratological category of "story" is relocated with particular instantiations (products), while the analysis of the process (as userly performance (cf. Knoller (2012))) can be given proper analytical space.

Cross-References

- Game Writer's Dilemma: Context vs. Story
- Hypermedia Narrative as a Tool for Serious Games
- Narrative Design
- Storytelling in Virtual Reality
- Virtual Reality as New Media
- Visual Novel

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Natural Walking

▶ Spatial Perception in Virtual Environments

Natural Walking in Virtual Reality

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Synonyms

3D user interfaces; Virtual locomotion; Virtual travel

Definition

Travel, or locomotion, is a fundamental and universal task within virtual reality (VR). However, enabling users to freely walk through virtual environments (VE) poses a considerable problem when the VE is larger than the tracked physical space.

Introduction

To most people, the act of moving from one place to another (i.e., locomotion or travel) is a common everyday activity. Similarly, locomotion is a fundamental and universal task within virtual reality (VR). Yet allowing users to freely navigate virtual environments (VEs) on foot is anything but a trivial challenge with respect to virtual reality. In the VE the user's movement should only be constrained by the virtual topography and architecture. However, in reality the user's physical movement will always be limited by the size of the tracking space.

Locomotion Techniques for Virtual Walking

The literature on virtual walking describes numerous locomotion techniques intended to facilitate unconstrained walking in virtual worlds that are larger than the tracked physical space. These techniques may be broadly divided into three categories:

Repositioning systems are designed to ensure that users remain relatively stationary by canceling out their forward movement. Examples of virtual locomotion devices include linear and omnidirectional treadmills (Feasel et al. 2011), motorized floor tiles (Iwata et al. 2005), cancellation of steps using strings Iwata et al. (2007), a human-sized hamster ball (Medina et al. 2008), and friction-free platforms Swapp et al. (2010).

The second category, *gesture-based locomotion*, comprises techniques requiring users to perform a gesture serving as a proxy for actual steps. So-called walking in place (WIP) techniques are a common gesture-based approach where virtual movement is generated from on the spot stepping-like movements (Nilsson et al. 2013a; Slater et al. 1993; Wendt et al. 2010, for example). Alternative gestures include, but are not limited to, arm-swinging (Nilsson et al. 2013b), head swaying (Terziman et al. 2010), shoulder rotation (Guy et al. 2015), and hip sways (Nilsson et al. 2013b).

The final category *redirected walking* manipulates the physical transformations of the user's movement within the virtual environment so that motion is no longer mapped 1:1 (Razzaque et al. 2001; Suma et al. 2012a), or manipulates the characteristics of the VE (Suma et al. 2011, 2012b). These manipulations make it possible to guide the physical path of walking users to travel through virtual environments that are larger than the physical space.

Conclusion

Most of the techniques belonging to these three categories have their merits. However, they come with unique benefits and limitations. While repositioning systems can confine the user's movement to an area of limited size, most current implementations are relatively cumbersome and expensive. Gesture-based locomotion offers an inexpensive and convenient alternative. However, the absence of actual steps enables only partial proprioceptive and kinesthetic feedback. Moreover, repositioning systems and gesture-based locomotion are designed to limit translational movement and therefore limit vestibular self-motion information. Redirection techniques involve actual walking which constitutes a considerable advantage. However, most redirection techniques demand a large physical walking space in order to be deployed without detection. Natural walking in VR remains an active area of research where existing techniques continuously are being refined and new techniques regularly are proposed. For a comprehensive overview of this body of work, see the book *Human Walking in Virtual Environments* (Steinicke et al. 2013).

Cross-References

► Locomotion in Virtual Reality Video Games

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Navigation Artificial Intelligence

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Synonyms

AI Motion; Locomotion; Path planning; Steering

Definition

Navigation is the set of processes used to guide the movement of an artificial intelligence (AI)-controlled agent. It is generally divided into three phases: path planning, to find a path through a static environment; path smoothing, to avoid unnatural motion; and steering, to compute the current velocity needed to follow this path while avoiding other agents.

Introduction

Navigating an AI in a game is a classic AI application. It was the first type of AI system to be created as middleware and represents one of the biggest reusable parts of most games, mostly because of the complexity and robustness needed to complete this task. Within a large game world, it is not possible to edit the navigation data by

hand. Automatic generation must therefore be used and be robust enough to cope with a wide range of worlds.

Moreover, AI navigation is a critical system: an error will create an obvious bug like an agent turning in a circle indefinitely or going in the wrong direction. More difficult problems arise with crowds, where deadlock problems can occur. Such problems will break the immersion of the game. Even a simple animal such as a mouse is able to find its path; this fundamental functionality has been acquired over millions of years of evolution and is so basic to human beings that an error in navigation is not forgivable for the AI.

Because local navigation methods can become trapped in local minima, a proper solution would be to use a search algorithm. We hence first focus on how to represent the navigation data and how to find a path for a single agent. Then, we briefly mention a method for smoothing this result and how to coordinate the motion of different agents.

Path Planning

The goal of pathfinding is to ensure that an AI can move in an environment without becoming stuck in a local minimum. For instance, in Fig. 1, the agent should not travel directly toward its target on the left, but follow the obviously correct path by first going right. Even if a local method can work well in some environments (e.g., outer space populated with small meteoroids), local methods often become trapped in local minima or yield unrealistic motion (i.e., they follow a wall on one side to escape a labyrinth) for an agent that moves inside a well-known environment.

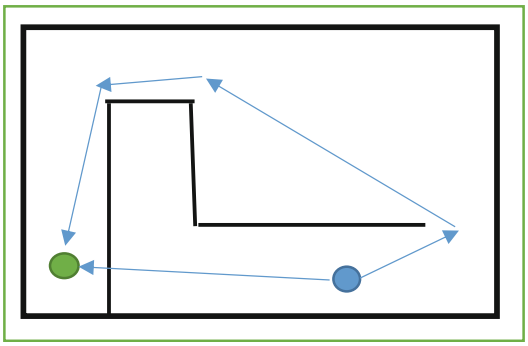
Pathfinding is a search algorithm to find the shortest path inside a navigation graph. This section first describes commonly used navigation data, and then the pathfinding algorithm A∗ is briefly presented followed by several of its optimizations.

Navigation Data

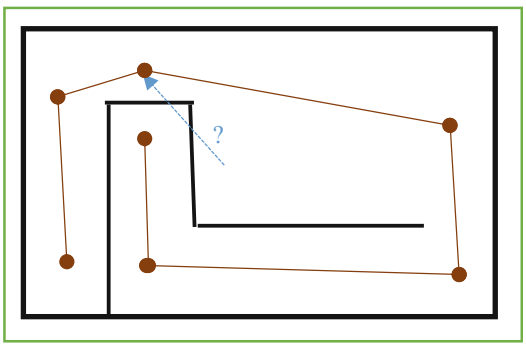
Before even considering how to look for a path, a suitable data representation should be determined. It is in fact not efficient to use direct collision data: a much lighter model should be used, as described below.

Waypoints

In computer science, the waypoint system is one of the oldest navigation representation systems for the pathfinding task. This system consists of a graph node in which the edges represent possible motions between points (nodes). Figure 2 shows an example of such graph. The main problem with such a graph is a lack of information about the paths not defined by the graph edges. That is, we do not know if it is safe to move outside this graph. It is still a very easy and natural way to set up navigation and can be combined with other



Navigation Artificial Intelligence, Fig. 1 Example of pathfinding. The path in front of the agent is a dead end. First, the agent must make a detour to reach its target



Navigation Artificial Intelligence, Fig. 2 Waypoint graph for locomotion. Note that once the agent moves off of the edges, there is no guarantee it will be able to reach the next node

methods described below to either give a designer the ability to edit the preferred route for crowd flow (Bernard 2008) or generate a more abstract hierarchical graph on top of another method to speed up pathfinding over long distances (Gravot et al. 2013; Alain 2018).

Grids

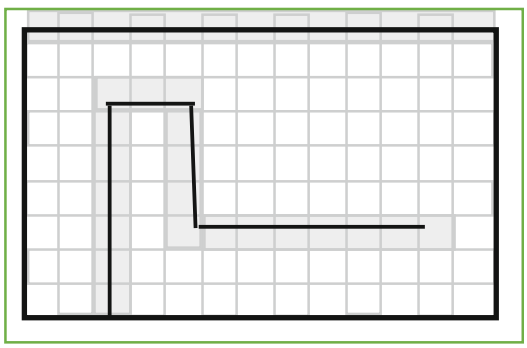
The grid system stores a world's connectivity inside a two-dimensional (2D) grid. This can be very efficient if the game design matches this representation. It was also the first system to enable some version of automatic generation. Because each cell is the same size, it is possible to use a flow field to compute the desired motion in each cell in one pass. This method is very convenient for crowd motion when all agents have the same goal (Mika and Jack 2013; McCarthy 2017). The main drawbacks are the memory cost and the number of nodes that must be explored to find a path. In contrast to the waypoint system, the grid system (Fig. 3) provides connectivity information for the entire space, allowing an agent to move freely within the world.

Navigation Mesh

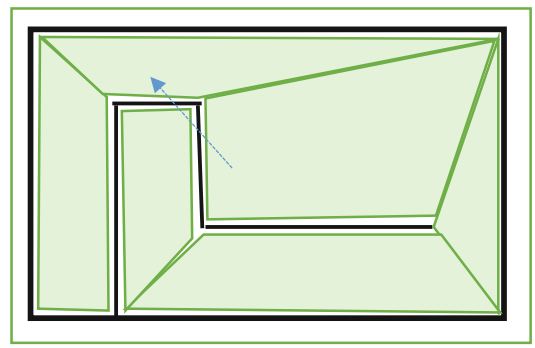
To be able to scale up the navigation system to a large world, instead of grid, it is possible to use a mesh composed of convex polygons (Fig. 4). The graph is then represented using polygons as nodes and adjacent polygon edges as graph edges. Since Miles (2006) and the release of the MIT-licensed Recast Navigation toolset (https://github.com/recastnavigation/recastnavigation), the automatic generation of such meshes from collision data has become widespread. Now, a large amount of middleware exists to create such data (e.g., Recast, Havok AI, PathEngine, and NavPower). The original version is based on collision voxelization and is able to scale well with complex geometry, whereas new methods are based on geometric construction and can increase the precision of the resulting mesh (Havok AI, PathEngine). Similar to a grid system, a navigation mesh can cover all possible navigation data, but with far fewer nodes and hence faster pathfinding. It is also easier to support overlapping floors with connected slopes. This is the most commonly used navigation data for 2D locomotion in modern games. However, because nodes have different sizes, it is difficult to use a flow field and more tactical reasoning. For this task, waypoints, a grid, or a tactical point system can be used (Mika and Jack 2013).

Sparse Voxel Octree

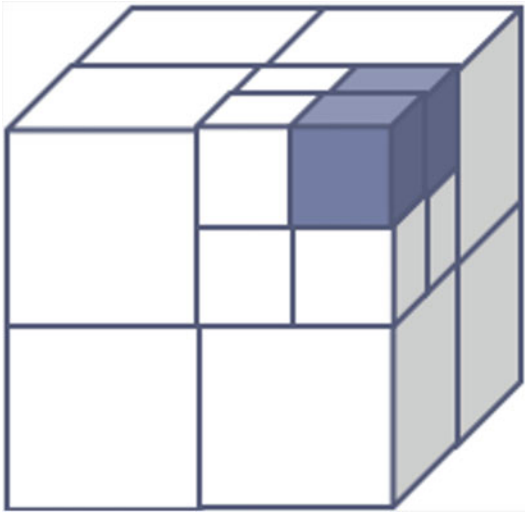
For 3D navigation, the 2D representations presented above may not be sufficient. The waypoint system can still be used, but to have real freedom of motion, an auto-generation method is needed. Similar to the grid system, a sparse voxel octree can be used (Fig. 5). For 3D navigation, there is often a large amount of free space in the world, and using a sparse representation can help reduce the data size. However, the size of the data and the



Navigation Artificial Intelligence, Fig. 3 Grid system for locomotion



Navigation Artificial Intelligence, Fig. 4 Navigation mesh for locomotion. With this representation, it is possible to find a path anywhere within the navigable area



Navigation Artificial Intelligence, Fig. 5 Sparse voxel octree for 3D locomotion. Each node can be split into eight smaller notes if there is a collision

pathfinding cost associated with it are still an extremely complex problem (Brewer 2017).

A∗ Algorithm

All pathfinding algorithms are essentially based on the A∗ algorithm (Hart et al. 1968). The only possible exception is when it is necessary to know the best path between any two nodes in the graph, in which case, the Floyd–Warshall algorithm is best (Cormen et al. 1990). However, even in this case, A∗ may be a better choice (Gravot et al. 2013) if paths over long distances do not require the best solution.

A∗ will find the optimal path within a weighted graph (such as the ones presented above), i.e., it will find the path with the lowest cost. For that, it uses a heuristic H(n) to estimate the remaining distance to the goal. As shown in the code below, the algorithm expands first nodes with the lowest total cost F(n), which is the sum of G (n) (the cost to reach that node) and the heuristic H(n).

For a consistent heuristic H(a) > = d(a, b) + H (b), A∗ can expand each node only once. Note that each node has only one parent. If the heuristic is consistent (i.e., its value is always lower or equal to the cost to reach the goal), the algorithm will return the best possible path. Note that some games use inconsistent heuristics to speed up the search process.

```
open_set := { start }
closed_set := {}
While not empty open_set:
    current := node in open_set with the
             smallest total cost F
     If current = goal
         Return path from goal to start
     open_set.remove(current)
     closest_set.Add(current)
     for each neighbor of current
         if neighbor in closest_set
             continue
         score = G(current)
                 + d(current, neighbor)
         if neighbor not in open_set
             open_set.Add(neighbor)
         else if score >= G(neighbor)
             continue
         neighbor.SetParent(current)
         G(neighbor) := score
         F(neighbor) := score
                 + H(neighbor)
```

Code 1: A∗ algorithm

Pathfinding Optimization

Pathfinding is still a costly task, and it is often a good idea to do some time slicing on it (at least to split the pathfinding requests on several frames). Most often it seems natural to have a small delay for reaction time so such time slicing will integrate well. Nevertheless, reducing processing for pathfinding can be needed even for one request. The first step can be to look at the navigation data. The less nodes to expend, the faster it will be. For similar precision, the navigation mesh will have less nodes than the grid, but with one more dimension, sparse voxel octree can be very costly. The other way can be to use one of the following optimizations.

Connectivity

One problem with A∗ occurs when there is no path. A∗ will then explore the entire connected space before returning false (to indicate there is no path). One possible solution is to tag a connected part of the environment and check for tag equality. When there are agents with different traversal capabilities, this will still result into a

graph search, but with far fewer nodes, and it is likely that results will be cached for the most common patterns. For dynamic environments or very large worlds, a hierarchical approach can be used (Gravot et al. 2013; Alain 2018) to reduce the update cost. In fact, a simple path added or removed may imply changing the tags of many data, but a hierarchical update strategy is a good way to reduce this cost. In that case the connectivity update computation complexity is O(log(n)) in the number of navigation data nodes. In practice the update algorithm is generally very light compared to the generation of new navigation data which triggers it.

Bidirectional A∗

Even if the start and the goal can be connected together, A∗ can explore many nodes before reaching the goal. Bidirectional A∗ has made recent progress (Sturtevant 2018) toward reducing the number of nodes that must be searched and never searches path that costs more than twice the optimal path. Even if it is slower than A∗ in many cases, it still avoids the worst cases of A∗.

Goal Bounding

This optimization precomputes the bounding volume of all the points for which the graph edge is the optimum one Rabin and Sturtevant (2017). Because this optimization can be performed on any type of navigation data, it is a very convenient way to speed up an algorithm. Then, at run-time, only edges that have a bounding volume that includes the goal need to be expended. However, this approach cannot be applied to dynamic navigation data. Precomputing the constraint is $O(n^2 \log(n))$ in the number of navigation data nodes.

Jump Point Links

This optimization results in a big speedup on grids with uniform weights (Harabor and Grastien 2011; Sturtevant and Rabin 2017). Moreover, it works without any preprocessing (although speedup can be obtained even with preprocessing). It works by using a set of rules to do a type of raycast, effectively exploring one direction until it reaches an obstacle. This algorithm uses the symmetry property of the grid representation and these raycast tests to reduce the number of nodes that need to be explored.

Experiments on *StartCraft*, *Warcraft III*, and *Dragon Age* maps have shown a speedup of more than 100 times with JPS+ (JPS with preprocessing) and more than 1000 times if also combined with Goal Bounding (Sturtevant and Rabin 2017).

Precomputed Paths

Precomputed paths can be used to speed up the search algorithm (Gravot et al. 2013) or to ensure consistent paths across the network (Cournoyer and Fortier 2015). This can also be a good way for optimizations based on level of detail (LOD) and crowds to share valid paths among agents. On one hand (Gravot et al. 2013), it is possible to precompute all possible paths and have a hierarchical lookup table to cope with the memory explosion problem. On the other hand (Cournoyer and Fortier 2015), we can precompute paths between waypoints and then generate a high-level waypoint graph with very few nodes and complex paths between them. In both cases the search space can be greatly reduced.

Hierarchical Planning

Hierarchical planning substantially reduces the search cost with losing the optimality where it does not matter, i.e., far from the start and goal (Gravot et al. 2013; Alain 2018). Within very dynamic environments where pathfinding is requested often, having an algorithm that is fast and precise near the start can make the AI move locally optimally without falling into local minima and becoming unable to reach the goal.

Such methods are normally based on node connectivity, and high-level paths can have a coarse estimation of the distance and bigger nodes.

Hierarchical planning can also be used for LOD. For very large worlds, all the navigation data cannot fit into the memory, but we would still like for the AIs to exist and travel on a path even when they are far from the player. An abstract waypoint graph can be used for long-

term pathfinding and can reside in memory for agent simulation (Lefebvre 2018).

Path Smoothing

Once a path has been found, it is generally not directly usable. This is especially true for dense representations like grids or navigation meshes. Even if a straight path exists, the path planner explores the graph's edges, which are not necessarily aligned with this path. The resulting path has often zigzags. Moreover, the planner often does not consider the kinematic constraints of the agent. It is often desirable to create a path able to respect them and to use the constraints to control the agent on this smoothed path, for instance, by slowing down before a sharp turn.

There are several example algorithms for dealing with these two problems.

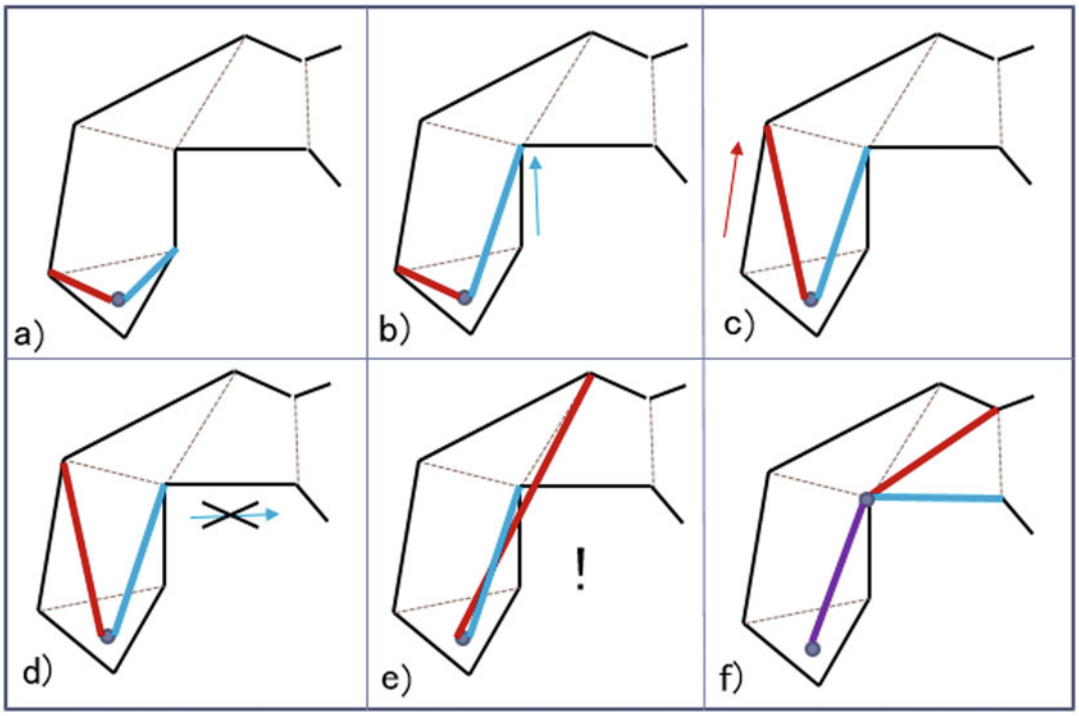
Funnel Algorithm

The funnel algorithm (Demyen 2007) is a very common path smoothing algorithm, especially for navigation meshes. In this case, the pathfinding determines a polygon path with a cost based on edge centers. However, a path through edge centers is far from optimal. Because we in fact have a path composed of polygons, any path going through them is valid. The funnel algorithm (Fig. 6) can find the shortest path within a polygon path.

The main drawback of the funnel algorithm is that it does not explore outside the channel. However, it can also be used for finding a first path before other algorithms are used.

Path Cut

The path cut algorithm is the simplest path smoothing algorithm. Two points on the path are chosen, and it is determined whether a straight-line path between would be valid (i.e., a



Navigation Artificial Intelligence, Fig. 6 Example of using the funnel algorithm to smooth a polygon path. (**a**) Start the funnel by expanding it. (**b**, **c**) The left side can only expand to the right and vice versa. (**d**) The right side cannot be updated. (**e**) The left side would cross the right one if it were updated. (**f**) A new waypoint is created in and a new funnel can start

navigation raycast check). If this is the case, the intermediate path is replaced with this line. This can be a costly algorithm, but after applying the funnel algorithm, the number of points that must be considered can be reduced.

Regardless, it is always advisable, even before finding a path, to use a navigation raycast to determine if the start and goal can be reached using a straight line.

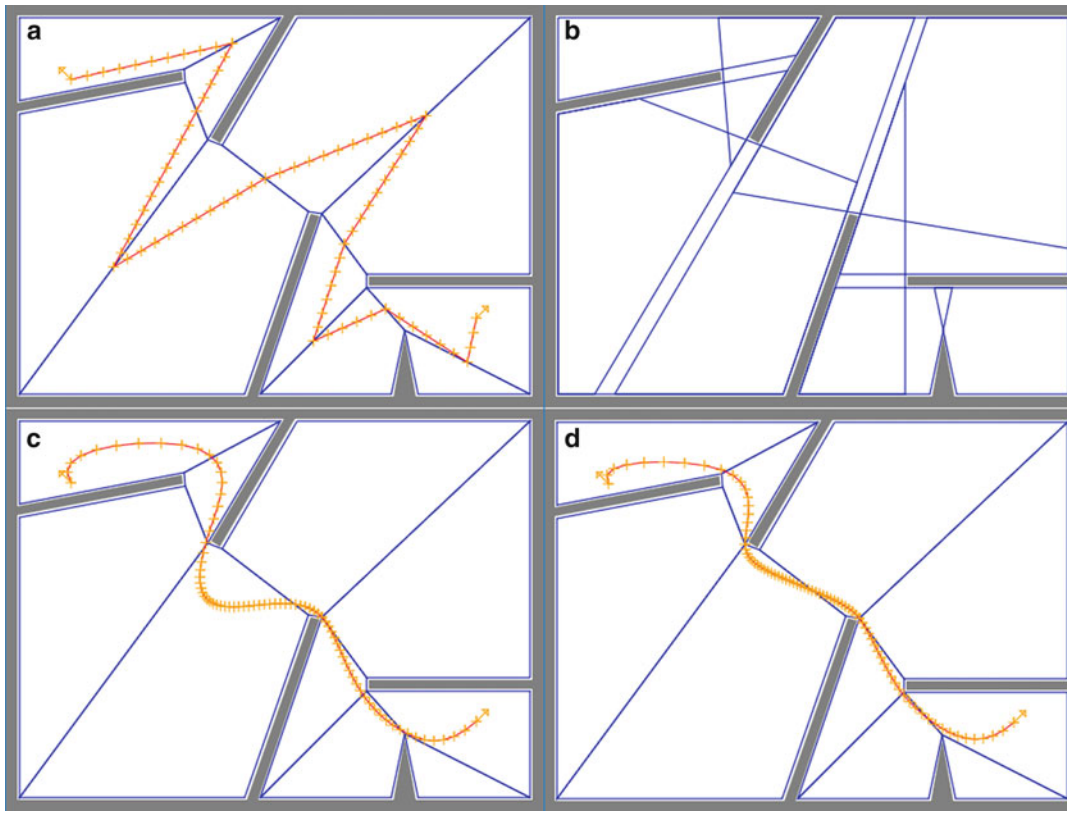
Adding Smoothing Constraints

Once we have the shortest path as a series of straight lines, it may be necessary to smooth it to respect the kinematics of the agent using it. Several methods can do this, but the best method to use will also depend on the complexity of the kinematic constraints. Bezier curves yield aesthetically pleasing but physically unrealistic motion. Circles ensure the continuity of the speed vector (but not the acceleration vector), and cycloids are curves used by road traffic planners, but are more complex to compute. The goal here is to add a smooth transition in place of each segment-to-segment transition.

To be complete, the algorithm must also check for possible collisions with the new curve. When collision occurs, sharper versions of the path with lower speeds can be used.

Path Optimization

Another solution to smoothing a path is convex optimization (Langerak 2017). The original path is sampled and each sample is associated with a convex volume on the path. The original method (Langerak 2017) was based on circles, but this can



Navigation Artificial Intelligence, Fig. 7 Example of path optimization above a navigation path. (**a**) Original unsmoothed path with the desired orientation at the start and end. (**b**) The main convex polygons used to constrain the path point locations. (**c**) Smoothed path. (**d**) Another smoothed path resulting from different smoothing parameters

also work with polygons built over the polygon path, as shown in Fig. 7. Just as for the funnel algorithm, this approach works only with valid path edges. Because it is an optimization problem, it is costlier than the other algorithms, but ensures path validity.

Steering

Once a path is found, the agent must follow it, but generally, it is not the only one in a world. It must hence coordinate itself with other agents. This is the goal of the steering algorithm. Most steering algorithms consist of three phases: computation of the desired velocity for following the path (or the current desired action); avoidance, which adapts the velocity to avoid other agents; and post-processing, which is used to create a more realistic model.

Desired Speed

Computing the desired speed is the first step of steering. Sometimes, for crowd simulation, a flow field is used to determine a desired speed on each point of the map. Sometimes the steering behavior of flocking agents, such as when fleeing a threat, can be used. This can be as simple as a direct vector-based computation (Reynolds 1999) or involve a tactical point system to find a goal with various conditions and avoid local minima (Johnson 2017).

When an agent is following a path, a part of the path smoothing can in fact be done here (Guðmundsson et al. 2017). For a dynamic world, there is no need to smooth too much ahead (unless it is a straight line), and adding the agent's kinematic constraints can help yield various types of desired motion. Path smoothing is still useful for finding the portals with transition points that need to be passed. This information can be used for detecting the next desired direction. Note that it is not good to attempt to move toward the waypoints themselves, as this can create artificial congestion. A path generally provides margins from which the portal can be defined. This enables the agent to keep some freedom for steering.

Avoidance

Avoidance is generally the core and the most expensive part of the steering algorithm. There are three types of avoidance algorithms:

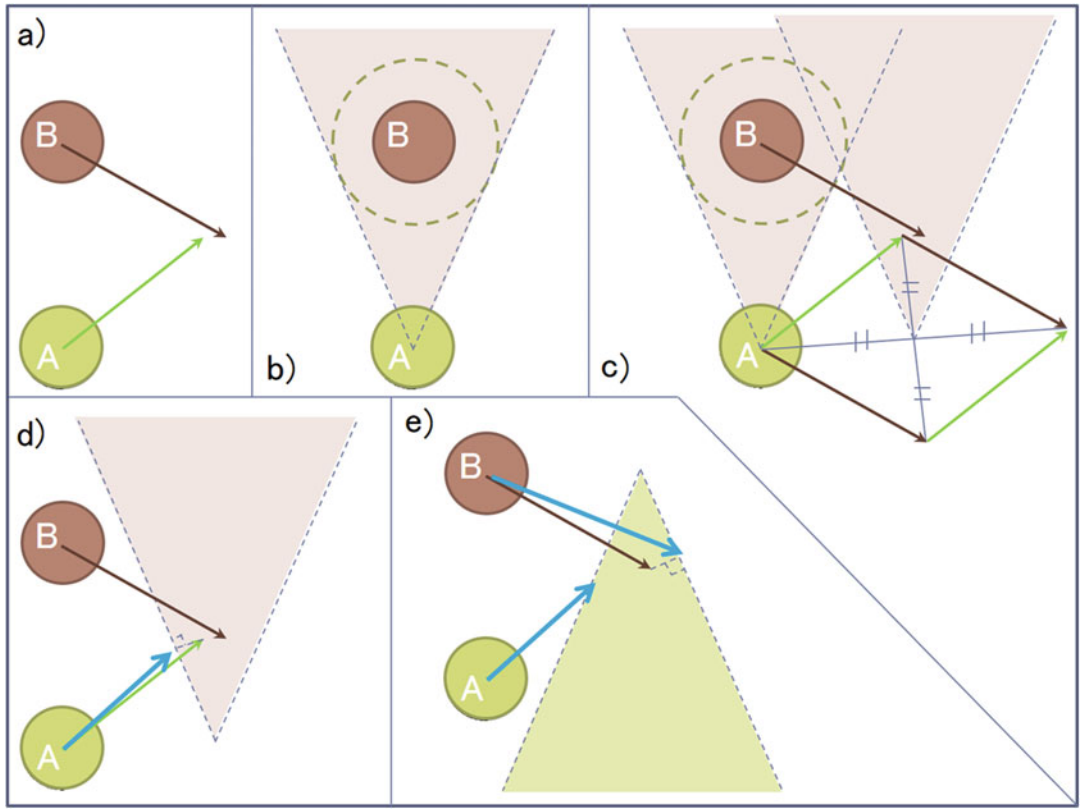
- Empiric algorithms, such as the Boids or Reynolds separation forces (Reynolds 1999) algorithms
- Robotic algorithms, such as reciprocal velocity obstacles (RVO; van den Berg et al. 2008) or the optimal reciprocal collision avoidance (ORCA; van den Berg et al. 2011.
- Sociological algorithms, such as the human-like (Guzzi et al. 2013) or force-based (Guy and Karamouzas 2015) algorithms

The empirical algorithms arise from simple experiences and the game industry. They are fast and tunable, although too much tuning may be required. The robotic algorithms give proof for no collision within a set of assumptions: notably perception and holonomic motion. As shown in Fig. 8, RVO computes the possible velocity in a set of constrained polygons in velocity space. ORCA is much faster because it uses a plan (but also removes possible solutions). These two algorithms generally form the default implementation of most navigation middleware. Even if the original assumptions are not respected, they still can yield good results. Note that tuning them is not necessarily straightforward (Sunshine-Hill 2017).

Social-based algorithms are based on measures of human crowd behavior and try to simulate similar behaviors. They have possible failure cases but yield results that may be more realistic. Moreover, their model is often closer to the ones used in games and may results in fewer approximations. Compared to agents following ORCA and RVO, agents following social-based algorithms more often force their way out of than run away from a crowd approaching on the other side, which is generally more realistic.

Connection with the Animation and Physics Systems

Most avoidance systems use a simplified model to compute avoidance. Hence, it is often necessary



Navigation Artificial Intelligence, Fig. 8 RVO algorithm. (**a**) Agents and their desired velocity. (**b**) The velocity obstacle of B toward A, computed by adding the radius of agent A to that of B. (**c**) Velocity obstacle projected into velocity space by sharing half of the responsibility of avoidance (the mean of the speeds of A and B). (**d**) Nearest valid velocity for A computed from the original desired velocity. (**e**) Nearest valid velocity for B is computed to obtain the two corrected velocities that avoid collision

to perform some temporal smoothing. For instance, a steering algorithm can use a wide range of speeds, but the agent may not have very slow motion animation. Low speed must often be dealt with properly.

Another important point is that collisions may still occur. It is still realistic or even desirable to have collisions in edge cases. Because an avoidance system can predict collision in advance, it is even possible to begin avoidance animation to make the collision look good.

Moving on Rails

There is one notable exception to the three-step system presented above: the navigation system of *Hitman: Absolution* (Anguelov et al. 2012). When more time is spent on path smoothing and preprocessing, it is more wasteful to perform steering avoidance. Moreover, steering always uses a simplified model, and the motion quality may decrease as a result. In *Hitman: Absolution*, the designers chose to show the agent's path to the player, and this one must not change.

It is possible to keep the path and coordinate the speed of the agent to avoid collision. For a deadlock on a narrow corridor, additional coordinate planning is possible (i.e., to make one agent allow another to pass by).

Conclusion and Discussion

This entry has briefly introduced many algorithms that can be used for the different steps of a

navigation AI. The goal is to enable agents to avoid local minima and find their path in a complex environment. Something that most animals are able to do naturally is still a complex problem for an AI, and it must be accomplished robustly. Methods continue to be proposed to either improve the quality or support dynamic environments within the time budget imposed. Note that using a processing queue, it is possible to time-slice the planning work while retaining more than enough reactivity.

The navigation AI was one of the first AIs to be used as middleware; the complexity and robustness of the navigation task justified such investment. Moreover, it was shown in this entry that it is possible to create increasingly more specialized awareness behavior. Not only paths, jumps, and vaults, but tactical decisions and other influence maps can be added to an AI navigation system.

Cross-References

- ▶ Meta Artificial Intelligence and Artificial Intelligence Director
- ▶ World Representation in Artificial Intelligence

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NBA 2K, a Brief History

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Synonyms

Basketball game; Simulation game; Sports game

Definitions

NBA – National Basketball Association, a professional basketball league in North America
NBA 2K – A series of basketball sports simulation video games

Introduction

NBA 2K is a series of basketball sports simulation games developed by Visual Concepts and published by 2K Sports annually. It is based on the National Basketball Association and recently the Women's National Basketball Association as well. NBA would have yearly releases after its initial release in 1999 (Justice 1999). The cover for the game each year would feature a player in the NBA who was dominant or influential. See Table 1 for the list of players featured on the various covers.

NBA 2Ks was originally published by Sega Sports with the first release on the Dreamcast in 1999.

NBA 2K2 was the third installment in the NBA 2K series released on the Dreamcast, GameCube, Xbox, and the PlayStation 2 with Iverson returning on the cover. NBA 2K2 was the last 2K to be published on the Dreamcast.

NBA 2K, a Brief History, Table 1 List of players featured on the NBA cover

2K Game	Player(s) on Cover
NBA 2K	Allen Iverson
NBA 2K1	Allen Iverson
NBA 2K2	Allen Iverson
NBA 2K3	Allen Iverson
ESPN NBA Basketball (2K4)	Allen Iverson
NBA 2K5	Ben Wallace
NBA 2K6	Shaquille O'Neal
NBA 2K7	Shaquille O'Neal
NBA 2K8	Chris Paul
NBA 2K9	Kevin Garnett
NBA 2K10	Kobe Bryant
NBA 2K11	Michael Jordan
NBA 2K12	Magic Johnson, Larry Bird, Michael Jordan
NBA 2K13	Blake Griffin, Kevin Durant, Derrick Rose
NBA 2K14	Lebron James
NBA 2K15	Kevin Durant
NBA 2K16	Stephen Curry, James Harden, Anthony Davis, Michael Jordan, Pau Gasol, Marc Gasol, Dennis Schroder, Tony Parker
NBA 2K17	Paul George, Kobe Bryant, Danilo Gallinari, Pau Gasol
NBA 2K18	Kyrie Irving
NBA 2K19	Lebron James
NBA 2K20	Anthony Davis
NBA 2K21	Damian Lillard
NBA 2K22	Luka Doncic
NBA 2K23	Devin Booker

In 2003, the fifth installment was ESPN NBA Basketball. It was released on the Xbox and PlayStation. This was one of the two times when ESPN had their name on a 2K title. This would also be the fifth and last time Iverson graced the NBA cover, making Iverson the only player to get on the 2K over five times and in a row.

In 2004, Sega published the sixth NBA title. NBA 2K in 2005 developed and published their own 2K for the Xbox and PS2 without the need for companies like Sega and EA to help them publish their games.

NBA 2K7 was released on PS2, Xbox 360, and PS3. It was the last 2K on the original Xbox.

NBA 2K8 featured Chris Paul on the cover as well as the Slam Dunk Contest and a legal playlist with 23 tracks.

NBA 2K Online was the next 2K. The game company Tencent brought 2K Online to Asian markets.

NBA 2K10 introduced Kobe Bryant on their cover. It was the game that finally introduced "MyCareer Player." This game mode would go on throughout the rest of 2K.

NBA 2K11 was the legendary 2K with Michael Jordan on the cover. It featured many modes related to Jordan such as the Jordan Challenges. This mode allows players to recreate the most iconic Jordan career moments, such as his 69-point game.

NBA 2K12 was the first 2K to have three different people on their cover: Magic Johnson, Larry Bird, and Michael Jordan. It was also the last 2K to be on the PS2. It implemented an "NBA Greatest" mode where players can choose and play with historic players and teams.

NBA 2K13 was the first 2K to add "MyTeam" focusing on building players' own fantasy team and playing against others online.

NBA 2K14 added Euro League teams and MyPark. MyPark takes their MyCareer player they have used grinded badges for and upgraded his stats so that they can take him to the park and play against other players.

NBA 2K15 added a small feature that allows players to face scan themselves into their MyPlayer so that it looks like they are playing in the NBA.

NBA 2K18 was the first 2K to be released on the Switch. It added different editions for the 2K: The Legend Edition and The Legend Gold Edition. The Neighborhood, another version of MyPark, made its debut in NBA 2K18.

NBA 2K20 was the first 2K to add the 12 WNBAs (Women's National Basketball Association) basketball teams.

NBA 2K MyCareer

MyCareer, a gamemode where players control their own story, was first featured in NBA 2K10 (Santos 2016). Before playing the game, players will be able to choose their build and archetype. Players can choose their height, weight, position, and wingspan. Building MyCareer players is what makes player characters unique before even starting a game. Starting as an upcoming prospect in college, the player's performance will determine when and to what team they will be drafted by in the NBA. Once drafted, they have the ability to improve their role on the team and earn more minutes based off of performance.

The ultimate goal on MyCareer is to achieve all the Hall of Fame requirements and finally retire from the NBA. MyCareer is so popular because players can become an NBA player and play for their favorite team. Even if that team is not any good, they can become their star player and win them a championship, which can be so satisfying with all the hard work they put into it.

NBA 2K MyPark

NBA 2K14 introduced MyPark game mode which became one of 2K biggest modes of all time (SGO Staff Writer 2021). It was not that big in 2K14, but it absolutely blew up in 2K15. It allowed players to take their MyCareer player and play against other real users in pickup style basketball. It offers rewards and a rep system where if players do well in a game they get rep/up. Players will start out as a rookie and go all the way to the destined Legend 3 where they can play as a mascot on the court. It became so

popular that streamers would stream and try to become the first Legend 3 player. It was RedCityBoi who was made famous the entire year.

NBA 2K15 also had different affiliations that were used for years after they were called Sunset Beach, The Old Town Flyers, and the Rivet City Rough Riders. This gave an even more competitive aspect to the game: Other players can come to parks and play against players, but they had to get their rep up to a "Pro 3" rank before players could travel to a rival park. 2K also had a big event where all the affiliations played against each other and whoever won the most would get a brand-new looking park.

NBA 2K15 also added The Stage, which was a more competitive MyPark. Players could also wager their in-game currency, VC, against the other team. If they won, they got it back plus the VC from the other team with a chance to win the jackpot that could go up to 7,000,000 VC. The last big edition that 2K15 had was the Jordan Recreation Center where players could play with any player.

NBA 2K16 was almost the same as 2K15 except that it had a different rep system. Instead of Legend 3, it went all the way to Legend 5. The rewards were cool for Legend 5. If he got a tiger, a tiger would follow him around in MyPark. The first to achieve this goal was DopeSwag who became very popular for the entire year.

NBA 2K17 featured a new mode called Park After Dark with famous DJs, such as DJ Premiere. It was a special night time themed park that was of course played in a night time setting. The basketball courts were highlighted in neon to create the nighttime aesthetic while still being able to play basketball.

NBA 2K LEGEND Reward

The reward before NBA 2K16 was Superstar 5 where players could have a jetpack and fly around the park. Players could also get different badges and stuff for their player. However, the big reward in NBA 2K17 that everyone set out for was LEGEND.

The LEGEND reward was to be immortalized in the next 2K which was NBA 2K18. At first nobody in the community knew what this meant. 2K even kept it silent, but they finally said that there would be a statue in the next 2K for everyone who achieved the goal of a LEGEND. The first person to achieve this goal went by the username OrlandoinChicago. The following 2Ks kept the same rep system and the Neighborhood, but they changed the rewards to be more vibrant.

NBA 2K MyTeam

NBA 2K MyTeam is another game mode that was popular among players (O'Neill 2021). MyTeam is focused on creating a 5v5 team that they can play online or as a single player. Players earn VC for use in obtaining packs or getting a good player for their team. Players can also win rewards on the online mode. For example, players can win a Derrick Rose card if they get to the very end of the Road to the Playoffs, but they must win a perfect game and cannot lose a single time to earn this card. There was also an auction house for cards, but players could not put up cards, they could only sell them. 2K based this auction house on how the players played in a game; if a player played badly, their card would go down; and if they played well, the price would go up.

There are different modes in MyTeam: Blacktop, Domination, and MyTeam Online.

Blacktop is similar to MyPark, but players can pick one of the athletes who are on their team, and they get two random cards. Players could get the two worst cards in the game or the best cards in the game. Then, they would play someone else who did the same thing as them.

Domination is the single player game mode where players pit their teams against other NBA teams. They will win packs for each star. Players need a certain amount of MT (MyTeam Points) to win stars. When collecting all 99 points, players will get a special player for free.

Finally, NBA 2K19 added MyTeam Unlimited with 250,000 tournaments. These tournaments were highly competitive and eventually determined who was the MyTeam champion.

Reception and Controversy

Like every game, there were many controversies among the 2k community. Since there was a new release every year, it often seemed that every game was similar to the one released the previous year with very few changes. Cheating was also a big problem in MyPark and MyTeam. Cheaters would often use a xim, a gaming input adapter that allowed players to make every shot. Microtransactions were also a big controversy among the free to play players. Microtransactions in 2k allowed users to upgrade their player quicker or buy better players in MyTeam. This created a big gap in the game between players who spent money on the game and players who were free to play.

Conclusion

The history of NBA 2K has had its ups and downs throughout the years. Despite strong competitions such as NBA Live (especially in 2008), 2Ks never gave up and the series has become one of the biggest franchises ever. NBA 2K offers popular game modes such as MyTeam and MyPark as well as not so popular modes like MyLeague and MyGM. The simulation game itself is what players have enjoyed for more than 20 years and still remains as the top simulation basketball franchise.

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Nearest Neighbors

▶ Machine Learning for Computer Games

Network Economy

▶ Game Prosumption

Network Resource Management

▶ Potential of Augmented Reality for Intelligent Transportation Systems

Network Security

▶ IPv6 Common Security Vulnerabilities and Tools: Overview of IPv6 with Respect to Online Games

N

Networked Gaming Architectures

▶ Online Gaming Architectures

Neural Networks

▶ Classical Learning Method in Digital Games
▶ Human Interaction in Machine Learning (ML) for Healthcare
▶ Machine Learning for Computer Games

Neuroevolution

▶ Constructing Game Agents Through Simulated Evolution

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▶ Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science

New Media

▶ Virtual Reality as New Media

New Media Art Work

▶ Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications

New Super Mario Bros. Wii, an Analysis

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Synonyms

NSMBW

Definitions

New Super Mario Bros. Wii is a digital game released in November of 2009 by *Nintendo* for the *Wii* gaming console.

Introduction

New Super Mario Bros. Wii was released in November of 2009 by *Nintendo*. *Nintendo* created the game for the *Nintendo Wii* gaming console, and it was a sequel to the *New Super Mario Bros.* game released in 2006 for *Nintendo DS*. The future iterations of the series include New Super Mario Bros. 2 (2012, Nintendo 3DS) and New Super Mario Bros. U (2012, Wii U). The game follows suit of the other Mario games, having Mario as the main character, with Luigi, Yellow Toad, and Blue Toad available as options for multiplayer mode. The game was first released in North America, Australia, and Europe in November, then in Japan a month later. In the USA, *New Super Mario Bros. Wii* sold 1,390,000 units in November 2009, making it the third best-selling game of the month behind the Xbox 360 and PlayStation 3 versions of *Call of Duty: Modern Warfare 2* (McWherton 2019).

Gameplay and Story

The gameplay for *New Super Mario Brothers* is especially exciting because each level holds its own challenges and rewards. The game is based around eight worlds, not including the secret ninth world that appears after the completion of all the others and the collection of special coins. The game remains interesting due to the fact that each world has a different theme with unique enemies and twists. Within each world, there are somewhere between 10 and 15 levels that must be completed in order to continue. Along the way, there are toad houses that are placed and played solely to give the players rewards and helpful items. In order to complete each level, the player must make it to the end of the level and attach itself to the flagpole to signal completion. At the end of each world, there is a castle with a different Koopaling waiting inside. To complete the castle and unlock the new world, you must defeat the Koopaling for that castle. At the end of the very last castle of the game, Bowser Jr. must then be defeated in order to win the game.

The storyline of the game follows similarly to the original Mario-based games. The replication of the series story in each iteration has been offered as a "audience-targeting strategy" (Smith

2015). Princess Peach is kidnapped from her birthday party by Bowser Jr. and the Koopalings. Mario, and occasionally Luigi and the toads depending on if it is multiplayer or not, spend the rest of the game fighting the enemies at the end of each world in an attempt to save Princess Peach. If the player reaches the end of the game and is able to defeat Bowser Jr., then Peach is released from her cage and saved. Princess Peach and Mario are then able to float away in a hot air balloon together and live peacefully.

This repetition of story where Princess Peach gets kidnapped and victimized has been criticized by Feminist Frequency's seminal video "Damsel in Distress: Part 1 – Tropes vs Women in Video Games" (https://www.youtube.com/watch?v=X6p5AZp7r_Q&list=PLn4ob_5_ttEaA_vc8F3fjzE62esf9yP61) and played a pivotal role in the emerging of #Gamergate Controversy (Burgess and Matamoros-Fernández 2016; Massanari 2017).

Reception

The popularity of the game could also be attributed to the spike in Wii gaming consoles as a whole. "On January 31, 2010, the Wii became the best-selling home video-game console produced by Nintendo, with sales of over 67 million units (surpassing those of the original Nintendo Entertainment System)" ("Wii Sales," 2020). The console became a new, must-have thing at the time. Parents supported it because it offered many family-friendly game options, it was user-friendly for all ages, and it encouraged multiplayer inclusiveness.

Some of the main criticisms of the game were that it felt like a step in the wrong direction as far as the cutting-edge technology. Especially with "new" in the title, many people were expecting a major upgrade in graphics, 3D technology, and more unique gameplay. However, the game was created to fit into the typical Mario Bros. series, so not much was changed in order to preserve the aesthetic. As far as the use of cutting-edge technology, Nintendo purposefully decided to stick with 2D technology and non-HD resolution (Gipp 2019).

Overall, the New Super Mario Brothers game has been played and enjoyed by many throughout the years. It achieved record sales across the world upon release. It is an exciting and well-designed game that has stood the test of time as far as gameplay and inclusion. Some might have wished that Nintendo had utilized more advanced technology at the time, but ultimately the game fits the Super Mario Bros. series well. All in all, it is a must-play if you have not already.

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Newsgames

▶ Political Game Design

NFT

▶ NFT Games

NFT Games

The Revenue Models

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Synonyms

Blockchain games; Digital collectibles; NFT; Nonfungible tokens

Definition

Nonfungible tokens (NFTs) are blockchain-based virtual assets that have unique information and ID codes that identify them from one another.

NFT games include player interactions, the purchase of avatars and weaponry, and the ability to produce cash from NFT games via the play-to-earn (P2E) model such as the popular game, Axie Infinity.

Introduction

NFT games are those that incorporate NFTs in some way. Unlike other types of NFTs, NFT games include player interactions, the purchase of avatars and weaponry, and the ability to produce cash from NFT games via the play-to-earn (P2E) model such as the popular game, Axie Infinity. In addition, the developers can also write smart contracts that define the rules for the NFTs utilized.

Introduction to NFTs

Nonfungible tokens (NFTs) are blockchain-based virtual assets that have unique information and ID codes that identify them from one another.

People cannot swap NTFs for other assets, unlike cryptocurrencies, which may be easily traded on platforms. That also means that the value of one NFT cannot be the same as the value of the other.

NFTs, also known as digital passports, are digital representations of assets that are linked to the collectors' market.

However, other forms of NFT do exist. The increased interest in NFTs is due in part to their potential economic development and investment possibilities.

Characteristics of NFTs

An NFT must adhere to four fundamental rules:

- It cannot be copied.
- It cannot be imitated.
- It cannot be created on demand.
- It has the same ownership rights and assurances of permanence as Bitcoin.

Each NFT signifies something unique, authentic, and different, similar to collectibles. They have essentially distinct worth and cannot be exchanged (Conti 2021; Nanowerk 2021; BusinessToday 2022).

In the case of digital assets, a creator can additionally receive royalties every time the NFT is sold or exchanged.

Types of NFTs

Artworks

The vast majority of NFTs in use today are works of art – digital arts account for 99% of all NFTs. This is due to the fact that artists were the pioneers to seize and earn from the sale of their digital artworks NFTs. Virtual artworks such as digital photos, GIFs, and short movies are now being sold online as if they were tangible goods. To top it all, such NFTs have been sold for millions of dollars.

Antiques and Collectibles

Collectibles were the first NFTs to be introduced. They are digital versions of tangible artifacts such as Pokémon cards or vintage mint condition toys.

Curio Cards was the first significant NFT collectibles to be released. Since then, other collectibles such as Bored Ape Yacht Club, Cryptopunks, Cat Colony, Meebits, and others have taken off and traded at high prices.

Sports Memorabilia

Sports Memorabilia is one of the most popular NFT categories, with the NBA Top Shot being the most well-known example.

This form of NFT typically contains a video clip of a noteworthy sporting event. The LeBron James Dunk, a video clip showing Lakers star LeBron James dunking the ball, is one of the most well-known NFTS in this category. It was one of the most valuable Sports Memorabilia NFTs ever sold. How much? The NFT video clip was sold for more than $380,000!

Music

Music is also high on the NFT radar. For decades, music has been a fungible product, produced and distributed on records, cassettes, CDs, and digitally. However, musicians and DJs have recently started selling their work as NFTs, making some millions of dollars in a couple of hours.

Due to streaming platform and record label cuts, musicians often only receive a percentage of the royalties generated by their work.

When it comes to NFTs, musicians may retain nearly all of the money, which is why so many are opting to this lucrative option.

Events Tickets

NFTs may also be used as event tickets, making it easier to verify people's tickets and identities. Organizers of major events like concerts and music festivals can use a specific blockchain to create a restricted quantity of NFT tickets. These tickets may be obtained through auction postings and then kept on mobile devices via crypto wallets for simple access.

Real-World Tokens

Many people believe that NFTs will be utilized as real-world tokens in the future. The progress in the NFT area is headed in that direction, and the chances of it becoming a reality are good.

The cryptographic evidence of ownership provided by NFTs allows it to mirror real-world assets. Currently, many NFT initiatives are centered on the tokenization of luxury products and real estate. When you utilize NFT deeds to buy a house or a car, you have additional possibilities.

Domain Names NFT

Domain names are the digital real estate on which our businesses are built. Customers can contact us using a gateway provided by them.

Domain names have never been more precious or significant as they are now. The development of e-commerce in the USA coincides with growing sales of NFTs. This is particularly true for domain names in the NFT business. This digital real estate will become a destination for both NFT buyers and sellers with a memorable NFT domain name.

Furthermore, a domain name has many similarities to NFTs. They are all distinct, nonfungible, and have proved ownership.

What Are NFT Games?

NFT games are those that incorporate NFTs in some way (Cuofano 2021).

Unlike other types of NFTs, NFT games include player interactions, the purchase of avatars and weaponry, and the ability to produce cash from NFT games via the play-to-earn (P2E) model such as the popular game, Axie Infinity.

The allure of NFT gaming is that it generates unique and limited tokens that can be swapped with any other nonfungible token in a decentralized digital ledger based on blockchain technology.

This gives gamers actual ownership by giving them the ability to trade, build, and implement NFTs within a game.

In addition, the developers can also write smart contracts that define the rules for the NFTs utilized.

Popular NFT Games

Axie Infinity

Sky Mavis, a Vietnamese developer, produced Axie Infinity, a Pokémon-style game. It has over 350,000 daily active users, almost 40% of whom are in the Philippines, with Venezuela and the USA being the next two largest markets. The game centers around adorable fuzzy critters known as Axies, which players may breed, acquire, teach, and employ to perform challenges and combat online.

The goal of the game is to collect Smooth Love Potions (SLPs), which can then be used to produce additional Axies to utilize in the game.

SLPs can also be purchased and traded on a cryptocurrency exchange.

Top players are apparently making SLP1,500 (roughly US$435) every day from their Axies.

Alien Worlds

One of the most popular NFT game is Alien Worlds, with over 1.1 million users. This game earns Trilium (TLM), which is used to obtain control in the Planet Decentralized Autonomous Organizations, or Planet DAOs, and to unlock more games.

It replicates economic competitiveness and invites players to run for the planetary council or participate in council candidate elections.

Players in this NFT Metaverse may go on missions and find NFTs, which can subsequently be used to mine Trilium or fight fights and go on missions. NFTs are classified according to their rarity and shininess, which affect their worth in the game.

The Sandbox

The Sandbox is a virtual environment in which users may own and personalize one of the 166 thousand various land pieces. The landowners are allowed to do whatever they want with those land parcels, which are represented as nonfungible tokens on the Ethereum blockchain. They can develop games, virtual museums, or other creative endeavors.

The world of The Sandbox is built with Voxels. From that standpoint, it is extremely comparable to Minecraft. In The Sandbox, however, anybody may create a game, design trendy characters, and earn SAND tokens by fulfilling tasks. Because everyone in The Sandbox contributes to the game's environment, everyone wins benefits. That is what is termed as a earn-to-play revenue model.

Decentraland

The emphasis of Decentraland is on a decentralized economy within the game. The Ethereum blockchain is used to power the crypto game. You can purchase a plot of LAND and begin construction on it.

On these lots, you can build whatever you want. Everything from sculptures and malls to art galleries and movie theaters may be created.

You may either sell or monetize the parcel. A district is formed by a grouping of LANDs with similar themes.

Users in this district can vote to make changes to the district.

The initial auction resulted in the sale of all 90,000 LAND NFTs.

However, you may still purchase them on Decentraland's marketplace with MANA.

Star Atlas

Star Atlas, arguably one of the most anticipated blockchain games ever, is widely expected to set a new standard in the play-to-earn space by combining expansive space exploration gameplay, carefully designed strategy elements, and high-quality graphics to create what could be the first AAA-grade blockchain game.

The game's main focus is on space exploration, mining, and development. Players may design their own personalized ships, crew, and avatars, as well as build up mining operations as they travel around the cosmos. Ships also have warfare capabilities, allowing their owners to participate in PvP and maybe PvE fights for resources and control over various sectors. The majority of in-game assets will be recorded on the blockchain as NFTs and tradeable on the Star Exchange.

Sorare

Sorare is a fantasy football card game that allows players to establish lineups and strategies, making it the ideal NFT game for football fans.

Weekly contests pit participants against other managers using trading cards of professional football players. Like in fantasy football, your points are dependent on real-life events and the performances of the players in your deck.

Cards are classified into four rarity levels: limited, rare, super rare, and unique, which affect their worth on the platform. Players who possess these NFT cards can exchange with other players or sell on the open market for a profit.

NFT Games: The Revenue Models

Play-to-Earn Tokens

Most blockchain NFT games offer an in-game token (money) that can be traded or cashed out for other cryptocurrencies (GOBankingRates 2022). Participants in play-to-earn games are rewarded with digital currency or nonfungible tokens. These blockchain-backed games, also known as P2E, have gone widespread in recent years, becoming a major component of practically every metaverse.

Each platform has its own kind of cryptocurrency to compensate online players for their time investment. Smooth Love Potion, or SLP, is used in the cryptocurrency game Axie Infinity.

For example, it has two purposes:

- It is in-game cash
- An item used to breed characters

When you play Axie Infinity and win fights against Axies (axolotl-type monsters), you are awarded with SLP, which can be trade or cashed out.

Breeding New Tokens

With the introduction of NFT-based games came the breedable NFT.

Breedable NFTs are a fantastic chance for everyone who enjoys online gaming and designing new characters. This is because each platform has its unique breeding regulations. Thus, it is difficult to make broad claims about how breedable NFTs operate in general.

Roaring Leaders, a new NFT collection, for example, permits Roaring Leaders NFTs to be mated and produce Roaring Leaders cubs in a distinct collection.

The company also developed an innovative, Tinder-style dating system that allows Roaring Leaders owners to hunt for a "mate" if they lack both a male and female NFT to breed. Roaring Leaders, like all breedable NFTs, require token payment to be bred. The $ROAR token is used to pay for breeding on this platform.

Minting New Items

Players in metaverse games like as Decentraland and Cryptovoxels may build 3D items, wearables, and other collectibles and earn royalties from secondary sales. Because of smart contracts built on blockchain technology, players in Cryptovoxels can earn up to 10% of a selling price with each subsequent sale.

Players in other games, such as CryptoBlades, may create new weapons and sell them to the CryptoBlades marketplace. Players will be able to submit NFT collectable designs to the upcoming massively multiplayer online RPG (MMORPG) Ember Sword, and, if chosen, will be included to the game, allowing artists to earn royalties on secondary sales in perpetuity.

Staking NFT Game Tokens

NFT staking is the practice of keeping an NFT digital asset on a blockchain and hoping that its value increases over time.

You would be rewarded for keeping your NFT on that specific blockchain. These awards are frequently the protocol's native coin or NFTs.

If you received an NFT from a cryptocurrency game, your ownership would be recorded on a blockchain. An individual can hold on to the NFT and not sell it to anybody else.

The NFT has the potential to grow more valuable (or vice versa) than when you initially received it. As a result, the decentralized financial protocol

would reward you for preserving your proof of stake on its platform. As a result, it differs from NFT trading, in which you try to sell for a profit.

NFT Game Virtual Real Estate

The Sandbox games are decentralized in the sense that players purchase land in the game and can construct anything they want on it.

Minecraft and Roblox are the most popular Sandbox-style games today, with over 175 million users each.

Games like The Sandbox, Decentraland, and Axie Infinity are building the groundwork for players to own a piece of the games they play via NFTs. The blockchain game Decentraland, for example, has transacted over 98,000 ETH in virtual assets.

Another example is the sale of eight pieces of land in the virtual world Axie Infinity for a total of 888 ETH.

Anyone interested in NFT Game Virtual Real Estate Investment?

The right time in now!

Conclusion and Discussion

With three billion gamers expected by 2024, gamers will play an increasingly important role in creating the economics of the digital future. The gaming business is expected to earn $155 billion in revenue by 2020.

Thus, this is one of the most profitable ways to make money with NFT Games (Infostor 2022; Fintelics 2021). That is, if you have the skillset and the ability to attract players with your newly created NFT Game.

Analysts expect that the business will earn more than $260 billion in sales by 2025. This, combined with the growing popularity of NFT collections and NFT gaming, has firms wanting to create their own metaverse or NFT games to help them explore new boundaries in their business models, such as:

- **Increase your exposure and reach:** NFTs are all the rage in the digital economy and have a massive following among millennials. By investing in NFTs and NFT games, you can tap into the interest of a tech-savvy consumer base.
- **Increase revenue:** When an NFT gaming token is traded, developers – depending on the demand for the specific NFT game or in-game NFT – can earn more money.
- **Ownership exclusivity:** NFT games allow its owners to have total control on their assets. This is appealing since it allows gamers to earn cryptocurrency by selling NFTs. Furthermore, tangible ownership provides greater incentives to play a blockchain-based game and can be a consistent source of income.

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Nintendo Switch

► Super Smash Bros. Ultimate and E-sports

Nonfungible Tokens

► NFT Games

Nonlinear Music Composition

► Adaptive Music

Nonlinearity

► Animal Crossing: New Horizons and Its Popularity During COVID-19 Pandemic

Nonphotorealistic Rendering

► Post-Digital Graphics in Computer Games

Non-photorealistic Rendering

► Comic Arts in Games, Asset Production, and Rendering

NPC Non-playable Characters

► Genetic Algorithm (GA)-Based NPC Making

NPR

► Comic Arts in Games, Asset Production, and Rendering
► Post-Digital Graphics in Computer Games

NS-2 Simulation

► Simulation and Comparison of AODV and DSDV Protocols in MANETs

n-Simplex

► 2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making

NSMBW

► New Super Mario Bros. Wii, an Analysis

Numerical Methods

► Cellular Automata Methods
► Lattice Boltzmann Method for Diffusion-Reaction Problems
► Lattice Gas Cellular Automata for Fluid Simulation

Numerical Methods

► Lattice Boltzmann Method for Fluid Simulation

Nursing Education

► Nursing Education Through Virtual Reality: Bridging the Gap

Nursing Education Through Virtual Reality: Bridging the Gap

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Synonyms

3D simulation; Clinical skills; Healthcare training; Nursing education; Serious games; Virtual reality

Definition

Student nurses gain theoretical knowledge and clinical skills during nursing education; however, there is a gap between what they know and what they can immediately apply in an actual hospital scenario with patients. This can result in serious mistakes with repercussions on patient well-being and satisfaction. Over the years, Mankins and physical simulations have been used by student nurses to practice their skills in a safe environment; however, the advancements in technology have opened up a new paradigm of more realistic and immersive simulations (Hauze et al. 2019; Foronda et al. 2017).

A Manikin is the model of the human body, used for teaching medical or art students.

Virtual Reality (VR) is the use of computer technology to create an interactive three-dimensional (3D) world, which gives users a sense of spatial presence. Serious games are applications with serious purposes, developed using computer game technologies more often associated with entertainment (Ma and Zheng 2011; De Croon et al. 2018).

VR-based games and simulations provide safe environments in which nurses can practice their knowledge and skills repetitively in multiple contexts to reduce the time to competence and risk of failure on the job (O'Connor 2019; Weiss et al. 2018).

This entry touches upon the reasons why virtual reality and game-based approaches have been useful in bridging the gap between theory and practice for nurses.

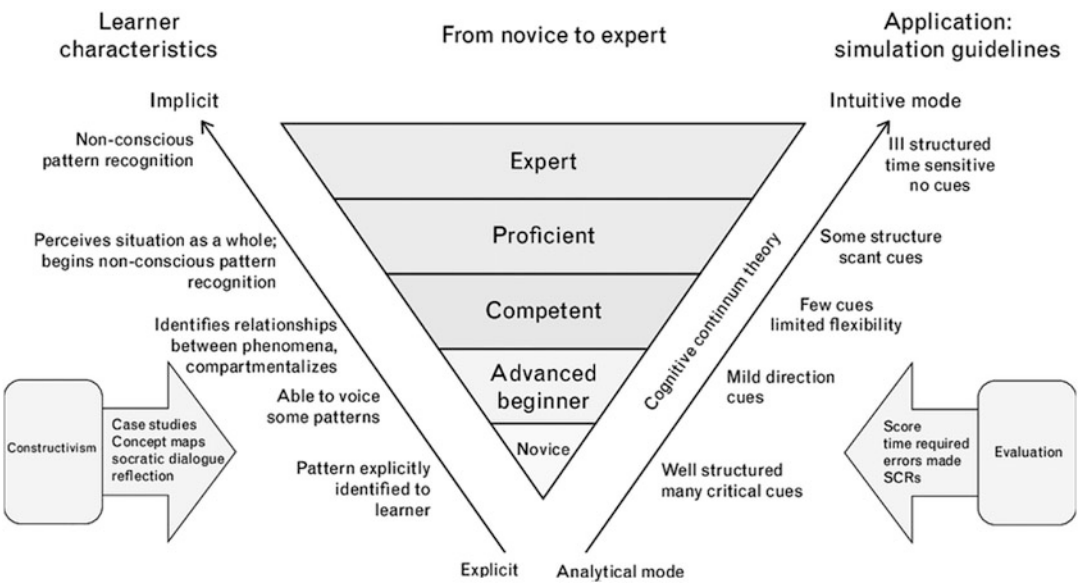
Introduction

Nursing professionals are often challenged to think critically, from simply "knowing," to analyzing and applying knowledge as they go about assessing and implementing patient care, often in high-stress environments. To this end, it is critical to get student nurses to fully understand what is wrong (or right) with the decisions they make and why, in a supervised or simulated environment.

Novel conditions, such as Covid-19 (Barello and Graffigna 2020), demand that healthcare professionals work effectively in situations of ambiguity and high risk. With rising trends toward outpatient care, nurses need to be decisive, communicate effectively, and perform complex problem-solving within a dynamic and changing environment. The global healthcare sector is increasingly turning to virtual reality, simulations, and serious games to create engaging learning experiences for doctors and nurses (Lu 2013). As technologies advance, games can be made more realistic and immersive through VR. The increasing number of affordable headsets such as Google cardboard, oculus go, and HTC Vive in the market and reduced latency factors due to 5G make VR more accessible, safer, and visually appealing. These innovative approaches promise new teaching and learning models that are far more holistic and engaging for the twenty-first-century learner.

Theories and Case Studies

The importance of practice in a real-world environment is proven from the early Constructivist Theory (Cetin-Dindar 2016) to Benner's novice to expert theory (Munjas 1985; Hassani et al. 2017), and Ericsson's concept of deliberate practice (Chee 2014). VR and serious games encourage practice, which helps the learner transition from



Nursing Education Through Virtual Reality: Bridging the Gap, Fig. 1 Benner's novice to expert theory (Hassani et al. 2017)

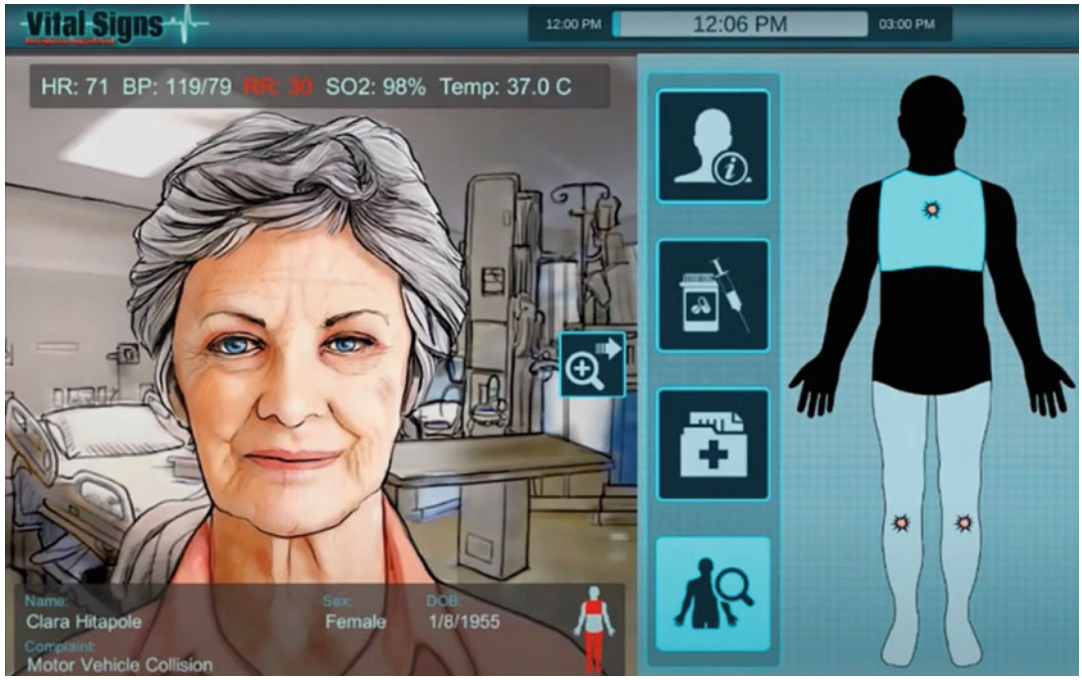
novice to expert, particularly in nursing education by providing learner control and a variety of leveled, realistic scenarios. This is particularly relevant for nurses given the wide variability and high-stakes nature of the tasks nursing professionals need to perform when they transition from a theoretical learning framework to a real hospital context (Fig. 1).

A study of 26 papers concluded that there are four core nursing competencies Serious Games can build among nurses: (1) Procedural skills, (2) Health assessment skills, (3) Communication skills, and (4) Clinical reasoning skills that relate to the core competencies of nursing (Tan et al. 2017). Research also demonstrates educational outcomes related to immersive technology include student learning, confidence, motivation, and engagement (Hauze et al. 2019).

Another research was conducted to understand the perception of nursing students about serious games keeping factors such as interface design, content, and effectiveness (Johnsen et al. 2018). In addition, the study assessed their perspectives on usability and future usage of serious games. A serious game prototype through two simulation courses was administered in nursing education: one for health care at home and one where the context was medico-surgical wards. Teaching clinical reasoning and decision-making skills for nursing students was the main focus of the serious games. Two hundred forty-nine nursing students in their second year took part in the pilot testing phase. There were more students who indicated that the home healthcare simulation course tested their clinical reasoning and decision-making skills. However, the students that played the medical-surgical and home healthcare simulations both indicated that more video-based serious games should be created for nursing education.

Another area where serious games are effective is in building problem-solving skills among students. Games can be adapted to meet a variety of healthcare needs through the patient life cycle from diagnosis to recovery. They can also mostly be played at any time in the day and from anywhere. Serious games are also easy to access, nonthreatening, and fun to play. Text, visuals, and audio cues improve the understanding of the learners without having the restriction of a brick-and-mortar classroom. Scenarios-based learning through games also allows for real-time feedback

that reinforces correct decision-making and procedures followed by the learners. Vital Signs by BreakAway Games – Serious Games Developer Vital Signs: Emergency Department allows learners to practice decision-making in the tension and chaos of an emergency department (Fig. 2).



Nursing Education Through Virtual Reality: Bridging the Gap, Fig. 2 BreakAway games: serious games developer

Nursing Education Through Virtual Reality: Bridging the Gap, Fig. 3 Virtual reality in nursing education: A look at VES available through pocket nurse|HealthySimulation.com

Vital Signs: ED™ – BreakAway Games

Virtual reality-based learning games enable student nurses to assess patients and objectively receive feedback in an immersive environment. Pocket Nurse's Virtual Education Systems VR-simulated learning platform uses avatars to immerse the user into an environment in which he or she would need to interact with a live patient. For instance, a nursing student could practice clinical skills and decision-making on a patient in a hospital setting (Fig. 3).

The student is given an understanding of the reason for clinical decisions and how they are made and also are given real-time feedback throughout the case. This form of experiential learning also drives behavioral change through the repetition of scenarios.

Conclusion and Discussion

Virtual reality as an educational strategy can build on procedural skills, diagnostic abilities, as well as higher-order critical-thinking, clinical decision-making, and communication skills (Lu 2013). Through patient simulations, critical elements of patient safety can be reinforced, such as prevention of errors in medication, practice of good communication, and understanding the importance of collaboration. Learners can be exposed to critical care scenarios and have the opportunity to respond without fear of harming a live patient.

Despite the fact that most studies have proven that VR and serious games help in building engagement and enhancing confidence, and are effective learning tools, there is still a need for addressing human factors such as giddiness through prolonged use (Chang et al. 2020) and ease of use of advanced VR headsets by nursing professionals.

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- ▶ Gamification
- ▶ Gamification and Serious Games
- ▶ Immersive Technologies for Medical Education
- ▶ Immersive Virtual Reality Serious Games
- ▶ Mixed Reality
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O

OBB, Oriented Bounding Boxes

▶ Spheres, AABB, and OOBB as Bounding Volume Hierarchies

Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design

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Synonyms

3D object manipulation; Augmented reality; Gesture recognition; User interaction

Definition

Augmented reality (AR) has the ability to blend the virtual and real objects. It enables users to interact with virtual objects or images with a real object as a medium of interaction. Hence, to provide natural and intuitive user interaction in AR environment, real hands are widely explored as an input. This entry explains the natural user interaction using real hand gesture in AR and explains the ARDeco application development process. The fundamental guide to developing AR application for interior design using real hand gestures with Leap Motion controller to interact with the UI and manipulate the objects with hand gestures, including color swatch and texture change panel for UIs and translation and rotation, scaling, create object, delete object, and clone object.

Introduction

Augmented reality (AR) is a technology that allows computer-generated or digital information that includes text, videos, and two-dimensional (2D) or three-dimensional (3D) virtual images to be overlaid onto the real-world environment in real-time setting (Azuma 1997; Mann et al. 2018). AR technology can be a potential solution to create an intuitive way of interaction with the digital content, as it diminishes the boundary between the physical and virtual world by merging them in a same space inside the real-world environment. Even though many research has been carried out in creating various ways in enhancing the experience in using AR,

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https://doi.org/10.1007/978-3-031-23161-2

interactions that are included in AR interfaces often constrained the users to interact freely and manipulate the AR content as well as prevent them from interacting with it more naturally and intuitively (Billinghurst 2001).

The use of conventional interaction in computers was common and has been used for most people until the current times. However, conventional interaction method that depends on mouse-keyboard-screen interfaces is divided between a space to act and perceive where the input and output devices are separated between virtual and physical spaces (Billinghurst et al. 2015). Hand gestures are one of the possible inputs that can be used in interacting and manipulating the AR content in a natural manner.

User Interaction in Augmented Reality

Researches in human-computer interaction (HCI) explore the ways for intuitive user interaction with an interface. Hand gesture is one of the most influential methods applied in HCI and one of the natural, ubiquitous, and important parts of spoken language (Lin and Schulze 2016). However, for mixed reality (MR), the Hololens device has used user's real hand gestures to catch user's input, while Magic Leap still uses controllers to capture user's input. Hololens and Magic Leap both run independently without the need of computer processing power because it already has its processing power installed within them making them wireless and mobile. Hololens also focused on the development of the virtual user interface (UI). According to Evans et al. (2017), traditional work on AR instructions provided by HMD is limited due to technological defects, but extensive works more into 3D UIs and user interactions can provide insight into potential solutions. However, 3D UIs need a change from 2D WIMP to 3D menus and interactions without a usual mouse. The biggest problem is that all user interactions must be intuitive and accessible through hand gestures rather than a wall, controller, or other physical instruments for optimal functionality. As presented in Table 1, holographic devices such as Microsoft Hololens (2016) and Magic Leap (2018) use a see-through lens in their headsets that enabled the user to see their physical environment while digital information is projected at their respective lenses. Holographic devices still allow the user to see their physical environment where immersive devices, such as

Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design, Table 1 Devices and experience

Characteristic	Holographic devices	Immersive devices
Example	Microsoft Hololens	Oculus Rift
Device		
Display	See-through display	Opaque display
Movement	Full 6DOF, both rotation and translation	Full 6DOF, both rotation and translation
Example	Magic Leap	HTC Vive
Device		
Display	See-through display	Opaque display
Movement	Full 6DOF, both rotation and translation	Full 6DOF, both rotation and translation

Oculus Rift and HTC Vive, purposely obstruct the user's view from the physical environment with their opaque headset and substitute the user's view with a fabricated digital environment. Table 1 shows the comparison between the holographic and immersive devices.

We examine one of the primary interaction tasks for the AR-based interior design application which is virtual object manipulation. Therefore, there is a need to enhance user's experiences in the augmented world by providing natural user interaction technique for natural and intuitive interaction (Ismail et al. 2015). Hence, there is a need for a better interaction device that uses natural hands and avoids the restriction of hardware between humans and machines to interact with virtual contents (Billinghurst et al. 2015) and promote six degrees of freedom (DOF) to make the experience more engaging in AR-based applications (Ismail and Sunar 2015). In addition, since AR technology is dependent on marker tracking and registration, the problem would be whether the marker is from interacting by hands or other means of physical objects (Azuma 2017); thus, it is important that real hand gesture interaction should be occlusion-free, that is, the hand should not block the marker for seamless tracking (Ismail et al. 2015). This entry aims to describe the implementation of gesture-based object manipulation technique for 3D interior design using real hand gestures in AR.

Virtual Object Manipulation

This section explains the related works and existing projects that have been done by others. Some of the notable works in Tangible AR interface are VOMAR (Kato et al. 2000), Move the Couch Where (Irawati et al. 2006), Studierstube (Szalavári et al. 1998), and FingARTips (Buchmann et al. 2004). As explained in VOMAR (Kato et al. 2000), it has produced a scene assembly prototype of an interior design application for AR. The application consists of a book that holds the virtual models of furniture, a large piece of paper as the workspace, and a marked physical paddle as the interaction metaphor to interact with the models. The virtual object can be manipulated with simple paddle gestures applied to it. Also, an extended and modified version of VOMAR (Irawati et al. 2006) integrates the existing VOMAR prototype. The prototype's functionality is still retained, but it integrates with a speech input system Adriane for specifying commands in object interaction and manipulation. Studierstube project (Szalavári et al. 1998) was a pioneer collaborative AR application that was meant to demonstrate the interface performance using 3D interactive media simultaneously in a collaborative environment. The users wear an HMD, allowing them to view the virtual models in collaboration as it superimposed in real physical world. FingARTips (Buchmann et al. 2004) is an urban planning-based workspace in AR environment that uses a vision-based interaction method in capturing the glove with fiducial markers applied on the wearable glove. The captured part of the hands (thumb and index fingers) can be used to pick up and place the virtual buildings around the workspace. The AR-based mobile manipulation application (Hürst and Van Wezel 2013) was developed to investigate the potential of finger tracking for the use of hand gestures in manipulating objects in handheld devices. This includes evaluation of canonical operations in basic manipulation techniques, such as translating, scaling, and rotating objects.

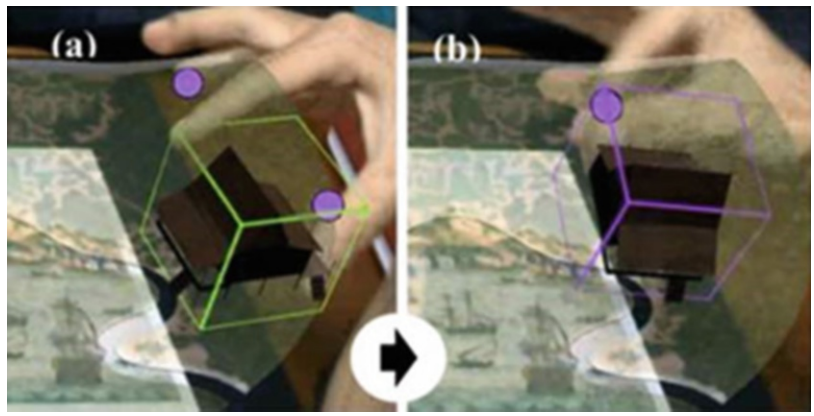
AR-based technology has provided users various interaction means with the virtual objects (Lin and Schulze 2016), and the progressive works in improving the current interaction issues are still ongoing until today (Kato et al. 2000). There is a need to have a better user interaction for AR-based application to make the user experience more intuitive and natural. By integrating virtual object manipulation with real hand gesture in AR environment for 3D interior design application, the user can interact with the virtual object more naturally and intuitively as it diminishes the borders of virtual and real-world environment.

As suggested by (Ismail et al. 2015), for the extended version of Ancient Malacca project (Ismail and Sunar 2015), they have developed an advanced method to improve the user interaction. They have implemented the multimodal

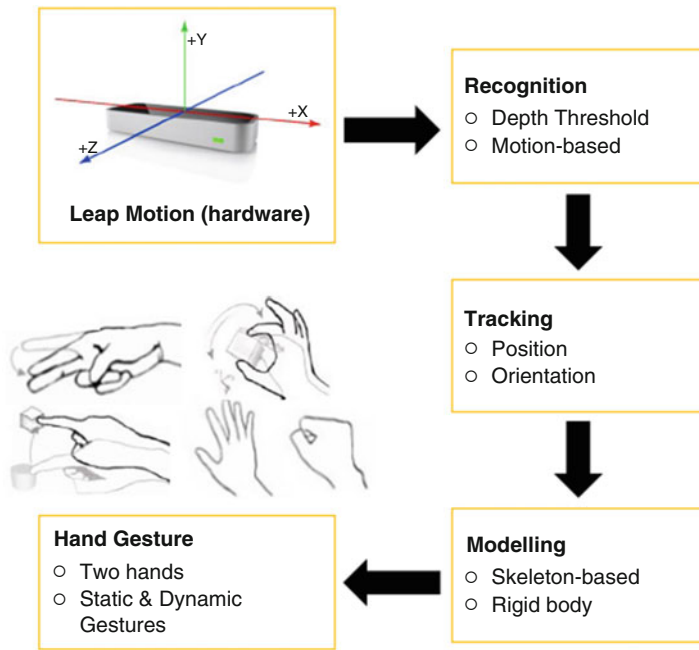
interaction using gesture and speech input, as presented in Fig. 1. The project has implemented the sensor-based hand tracking; the motion data is presented with virtual hand skeleton that is created every time the Leap Motion controller (Ismail and Sunar 2015) senses a real hand in the motion space. The hand skeleton is being drawn in the AR camera view consistent with the position of the image target. The key to high-precision natural hand gesture interaction is high accuracy and high degree of freedom (DOF) hand pose estimation. Their method has proven that it was able to provide 6 DOF natural hand tracking; tracking of the wrist, 15 joints, and five fingertips for both hands at 30 frames per seconds (fps).

Real Hand Gesture Tracking

The following sections describe the gesture recognition process that enables 3D object manipulation for natural gesture interaction using ARDeco (Syafiqa and Ismail 2018) as an example application.



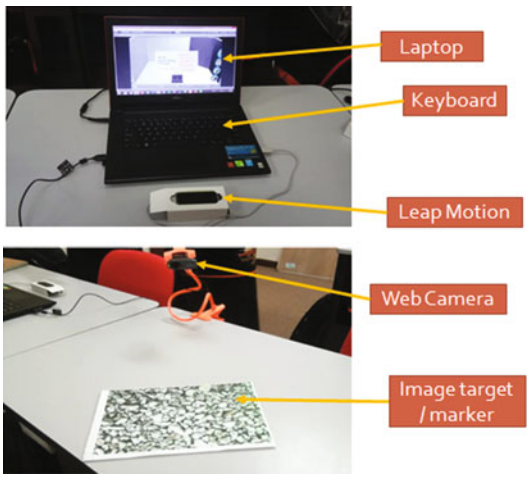
Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design, Fig. 1 Multimodal interaction technique (Ismail et al. 2015)



Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design, Fig. 2 Hand gesture tracking method

Stage 1: Gesture Recognition Process

For gesture recognition process, Leap Motion is being used to obtain a depth data. Four stages for the sensor-based recognition process need to be accomplished, as illustrated in Fig. 2. Firstly, the depth data is reproduced by Leap Motion in real time once the device captured the human hands. Next, the tracking process continued to produce pose estimation containing position and orientation. Then, the camera viewpoint pose estimation searches for the hand gesture skeleton to call the gesture shape and 3D representation for both hands. Leap Motion uses raw processing data to perform tracking. The motion data are processed with fingers, and 3D representation of what Leap Motion sees is reconstructed. After tracking the information, the fingers are extracted from the tracking layer. Position and orientation are used to map the 3D representation of the fingers and later used to invoke gestures. Gesture manipulations, including pinch, grab, and release, are implemented in the application. 3D hand skeleton-based interaction using a Leap Motion captures the hand skeleton and identifies 3D finger positions and orientations; thus, we can support a more natural hand gesture-based interaction in an AR scene.

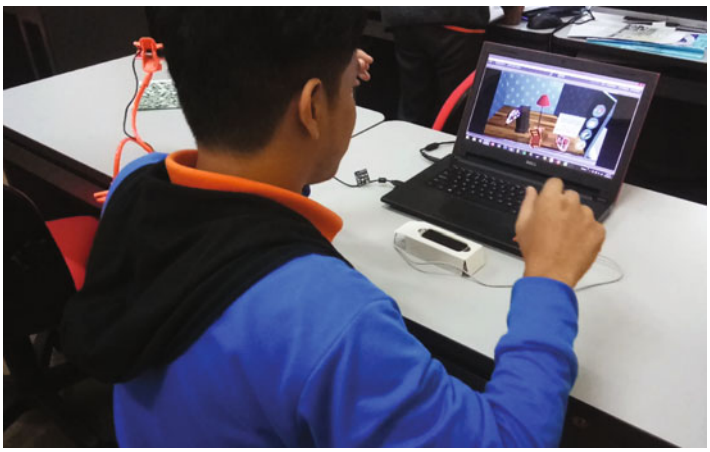


Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design, Fig. 3 ARDeco application setup

Stage 2: Performing AR Tracking System

The application acts as a platform to integrate the AR tracking with the gesture interaction for 3D object manipulation. For AR to work, the application uses natural feature tracking for more robust tracking. Figure 3 illustrates the AR tracking devices. A personal computer or laptop is used to execute the application; Leap Motion controller is attached to the computer for gesture recognition, while a web camera is used to capture the printed marker. The marker acts as an anchor for the AR environment.

In Fig. 4, AR interface focuses on discovering the manipulation techniques for manipulating virtual objects with hand gesture, including how the user interacts in the AR environment with gestures and basic three-dimensional (3D) spatial manipulation that can be done. ARDeco has come out with a technique for virtual object



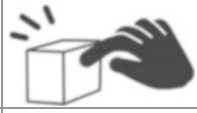
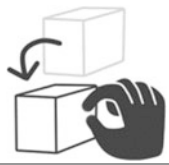
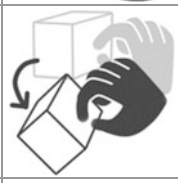
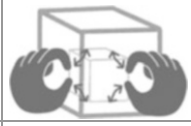
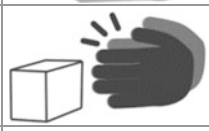
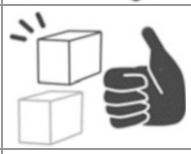
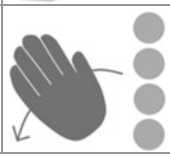
Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design, Fig. 4 ARDeco application with user interaction

manipulation to effectively provide an intuitive and natural way of interaction in AR environment. More about ARDeco will be explained in the next section.

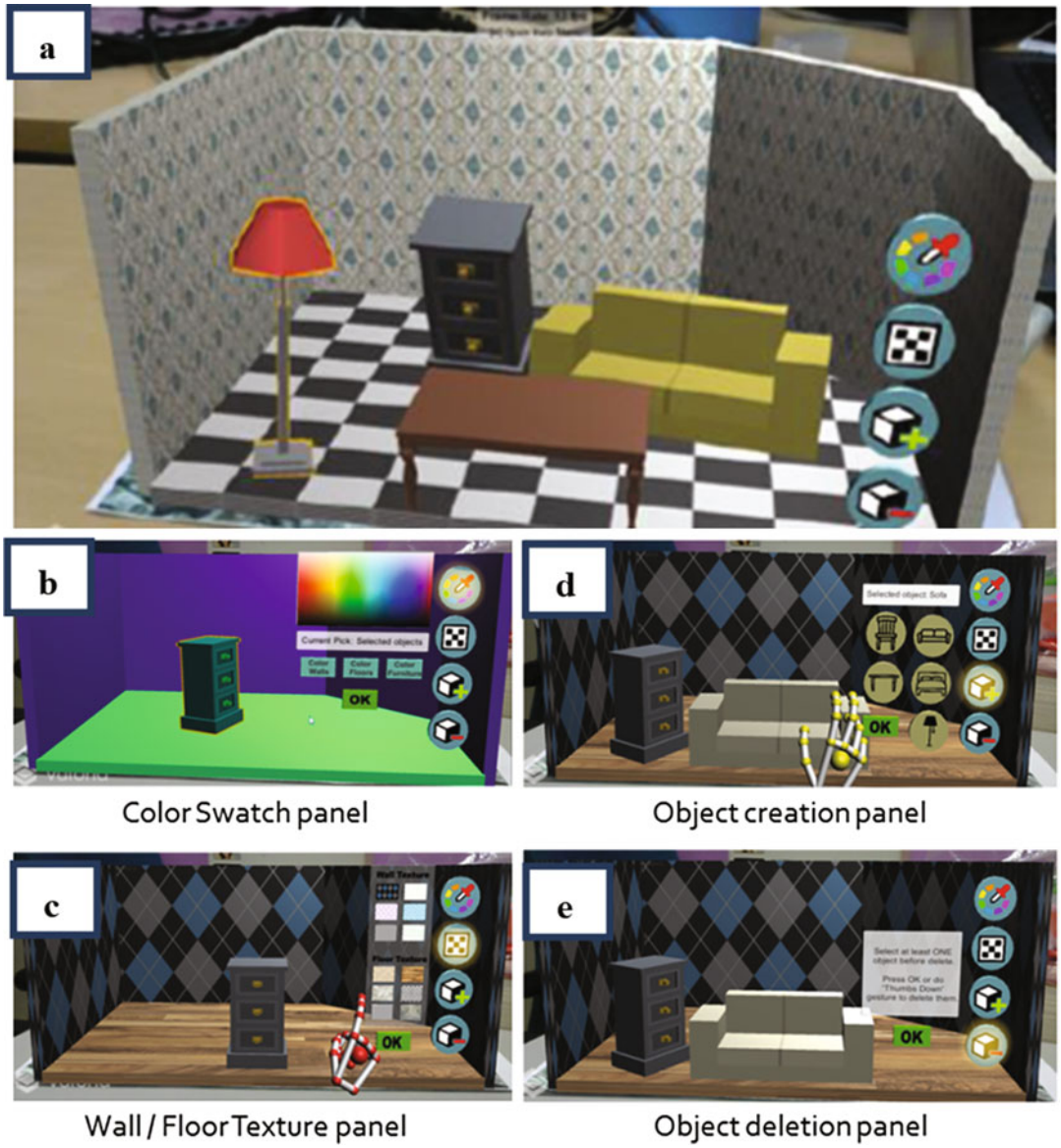
Stage 3: Acquiring 3D Gesture Inputs

The integration of virtual object manipulation using real hand gesture with AR application is described in this stage. The AR application is to use real hand gestures to interact with the virtual elements, including color swatch and a panel to change the virtual object texture. The 3D object manipulation such as translation and rotation, scaling, object creation, object deletion, and object cloning. These manipulation methods are implemented by ARDeco to run a robust virtual object manipulation technique.

Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design, Table 2 Manipulation task description

Task	Hand gesture	Gesture description
Select and deselect		Extend the index finger and touch the object
Translate the object		Pinch the object with the thumb and index finger to move it around
Rotate the object		Pinch the object with the thumb and index finger and pitch, roll, or yaw the hand to rotate the object
Scale object		Pinch the object with the thumb and index finger on two hands and extend the hands to enlarge or bring them closer to shrink
Create an object		Clap both hands by bringing the palms closer together
Delete object		Extend the thumb finger downward
Clone object		Extend the thumb finger upward
Call menu		Wave the right hand on a certain velocity

The hand gestures for object manipulation tasks such as select or deselect object, move and rotate object, and scaling object are implemented with some modifications. Other manipulation tasks such as create, delete, and clone object do not have specific hand gesture, but the new gesture for these tasks follows the guideline that has been recommended by (Nielsen et al. 2003; Piumsomboon et al. 2014). Common interaction approaches for 3D manipulation are translation, rotation, and scaling. On top of that, users are allowed to pick, drop, change, or remove the selected virtual content from the workspace. The user's real-time finger orientation and movement are obtained via Leap Motion device. Table 2 illustrates the gesture inputs that are used for manipulation task in ARDeco.



Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design, Fig. 5 ARDeco with real hand gesture interaction

ARDeco: Augmented Reality Interior Design

AR interior design, namely, ARDeco (Syafiqa and Ismail 2018), has a virtual panel that consists of four buttons that can be triggered by gesture in a small range of an AR scene called a virtual room. The room consists of several elements, which are four walls and a floor and a ground. There is also a furniture in the scene that is tagged with certain properties, and this furniture is manipulatable. The color and the texture of this furniture, as well as the walls and the floor, can be changed using gesture input by picking the desired colour inside the color swatch, and the texture can be changed by using the panel assigned to change the object's texture. The color swatch button consists of a color swatch image that can change the object's properties and the color of the furniture object's material. To initiate this function, the user needs to hit the corresponding button using gesture input where it can change the color in real time. After that, the user can use his hand in pointing pose by extending the index finger to select the desired color available on the color swatch panel. The ARDeco application has only five types of furniture, which are a sofa, coffee table, chair, sideboard, and lamp. The furniture would be spawned in the AR scene when a user hits the creation panel. To perform object deletion, the delete button needs to be hitted, and it will only work if an object or furniture is selected. Object selection can be performed by simply touching the desired furniture in the scene.

There are three basic manipulation techniques applied in ARDeco application, which are translation, scaling, and rotation. The user interface of ARDeco lets the user interact with the virtual buttons to perform the manipulation tasks based on gesture inputs. The translation action provides the relocation task, and rotation action gives the furniture's orientation value increase and decrease using the pinch method. The pinch method will be executed when the distance between the index finger and thumb reaches a certain threshold. The rotation action offers the ARDeco the ability to rotate the selected furniture based on the axes in AR interior scene. The scaling provides the furniture with the ability to resize. The task can alternatively be executed with keyboard commands. All of the methods mentioned above will only work if there is or are furniture selected.

Figure 5a shows the overall look of the ARDeco environment with the four buttons that can be seen on the right side of the figure. The virtual room consists of several furniture such as sofa, lamp, coffee table, and cupboard as well as the walls and the floor. The first button, which is the color swatch button, is for changing the selected furniture's color (as in Fig. 5b). The second button is for changing the texture of the selected object, and the user is given 12 types of textures to choose from (as in Fig. 5c). The third button which is the object creation panel is for adding new furniture into the AR scene, and there is a selection of five furniture types to choose from (as in Fig. 5d). The fourth button, which is the object deletion panel, is responsible for removing or deleting the selected furniture from the AR scene (as in Fig. 5e).

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Occluded Faces

► Digital Images Using Heuristic AdaBoost Haar Cascade Classifier Model, Detection of Partially Occluded Faces

On Computer Games About Cooking

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Synonyms

Cooking games; Gamification of cooking; Gamified cooking; Multiplayer cooking

Definitions

A cooking game is a game which gives the player/players an opportunity to gain, improve, or demonstrate knowledge or skills related to one or more aspects of cooking.

Introduction

The potential of computer games in teaching cooking remains underexplored despite the amount of consumed food that is not cooked at home, flexibility, control, cost savings and health benefits associated with home-cooked food, and disadvantages of some of the fast food. Limitations of current computer games about cooking include insufficient breadth or depth, resulting in the players getting inadequate knowledge about cooking, and limited ways of challenging the player, rewarding the player, or evaluating the player's performance. This article includes a brief but representative survey of computer games about cooking and introduces many new choices for addressing their limitations.

Cooking Games

Four levels of Overcooked! (https://www.team17.com/games/overcooked) are mentioned by Baek and others (Baek et al. 2022). It is a two-player

cooperative cooking game. One of the four levels requires the players to cooperate. Cooking itself is handled at a highly abstract level in (Baek et al. 2022). No specific recipes or specific missions testing knowledge of cooking, utensils, appliances, or eatable ingredients are mentioned in (Baek et al. 2022). The four levels differ in spatial distribution of tasks and whether the space is shared by the players or not. Bishop and others (Bishop et al. 2020) report on the utility of Overcooked2! in the study of human-agent and human-human teams. Overcooked2! is a game which requires a team of up to four players playing as chefs to complete as many food orders as possible in a short amount of time. Sushi, chicken, pasta, and burrito are mentioned in (Bishop et al. 2020) as the foods to be prepared while playing six levels of this game. The number of steps and ingredients in individual recipes aren't reported in this work.

Bista and Garcia-Ruiz present an overview of cooking games (Bista and Garcia-Ruiz 2021). Some of these are available as apps. Some of the important elements that are relevant to design of Chinese-cooking games are presented in (Cao et al. 2014). These include control over heat (off, extremely slow fire, slow fire, medium fire, and strong fire), ability to select seasoning (edible oil, salt, soy sauce, pepper, sugar, etc.) and other edible ingredients, and the ability to choose cooking action (shaking a spoon, stirring for frying, stirring, and removing and setting aside).

A virtual environment supporting single-player cooking and cooperative cooking for motor rehabilitation is presented in (Gorsic et al. 2018). It is designed to be controlled via wrist and forearm motions. There are three graphically distinct levels of this environment (*salad*, *pizza*, and *buffet*). Salad preparation requires selecting ingredients and dropping them into the bowl. *Buffet* level requires the player/players to locate the correct dishes and place them on the tray. There is an optional challenge that can be switched on and off. To solve this challenge, the player/players have to swat the flies headed toward the salad bowl, pizza, or buffet tray. This virtual environment was evaluated using five unimpaired men and seven unimpaired women. The evaluation involved the following five modes: (i) single player, without flies, (ii) single player with flies, (iii) cooperative playing without flies, (iv) cooperative playing with flies and undefined roles, and (v) cooperative playing with flies and fixed roles.

Dishcover (Mihardja et al. 2019) requires the player to fulfill the set of food orders placed by customers. The player is expected to select an order before its expiration time, but the player cannot select an order without fulfilling the order he/she is currently working on. This requires the player to consider the time needed to fulfill various orders, and prioritize. The actions to perform on an Android phone for frying, selecting ingredients, putting ingredients in the designated area, pouring, waiting, boiling, grilling, rolling, stirring, flattening, grabbing, shaping, and wrapping in the gaming world are described in detail in (Mihardja et al. 2019). The survey conducted to evaluate Dishcover asked the players to rate complexity of gameplay, ease of understanding the interface, immersion, reality, educational value, hours of content, and variety of content (Mihardja et al. 2019).

Express Cooking Train (Mitsis et al. 2019) is a game which expects the player to cook healthy meals that visually resemble junk food and launch them toward monsters to stop them from reaching the train controlled by the player. The player needs to ensure that the train travels farther to earn a higher score. The player is expected to experiment with new ingredients and techniques to enrich the recipes provided, to cook healthier food. Incentives for the player include new recipes, a higher score, and a faster and sturdier train. The player is evaluated based on the nutritional value of the meal prepared by him/her and its similarity with the reference recipe. Ontological modeling is used in calculating similarity with the reference recipe.

The cooking game in (Nakamoto et al. 2008) has an olfactory display. The olfactory display contains solenoid valves, quartz-crystal microbalance sensors, flowmeters with valves, a fluidic low-pass filter, 32 odor components, including the air component, a computer for controlling the solenoid valves, and an air pump. As the player adds ingredients, the player watches a movie on a separate computer and smells the

scent of each ingredient as it blends with those already in the pan (Nakamoto et al. 2008). Foodie (Wei and Cheok 2012) is a system which allows the player to create a food pattern on a mobile phone or tablet PC and craft it at the same or a remote location, e.g., using real sauce to create a message consisting of letters. Foodie is not a game, but it has some game elements. The food-crafting mechanism contains a robotic carriage and the attached food-depositing component with three syringes. The crafting process involves motors' movements and food extrusion. The authors state that the mechanism can only craft using viscous food materials with certain fluidity.

Digital World in Computer Games for Cooking

The world in computer games about cooking can be populated with a refrigerator, eatable ingredients, kitchen utensils, dinnerware, and cooking appliances, including automatic coffee maker, waffle maker, portable electric hot plates, cooking range, sandwich maker, blenders, mixers, microwaves, grills, and toasters. The eatable ingredients can be in different stages, for example, raw, fully cooked, partially cooked, marinated, frozen, sliced, diced, ground, peeled, shelled, or chopped. Diverse digital worlds can be generated by choosing the types of objects in it, the quantities of these objects, the states of these objects, and their spatial distribution. Besides core objects (appliances, utensils, and eatable ingredients), a digital world may have elements for assisting, obstructing, or entertaining the player/players.

Types of Core Challenges in Computer Games About Cooking

In this section, we identify many of the important challenges that can be presented to the players playing computer games about cooking. Many of these challenges are not offered by current computer games about cooking. The challenges are as follows:

(i) Recognizing an eatable ingredient
(ii) Recognizing the function of a kitchen utensil or cooking appliance
(iii) Finding if an eatable ingredient is ready to be used in the given recipe
(iv) Finding operations that need to be used to get the given ingredient ready for use in the preparation of the specified food
(v) Finding the utensils or appliances that need to be used to get the given ingredient ready for use in the preparation of the specified food
(vi) Ordering the given, unordered or incorrectly-ordered steps of a full or partial recipe
(vii) Recognizing the ingredients relevant to the preparation of the specified food
(viii) Recognizing the utensils or appliances relevant to the preparation of the specified food
(ix) Finding whether the given quantities of ingredients are adequate, too less, or too high for preparation of the specified number of servings of the specified food
(x) Estimating the quantities of the given ingredients that are needed for preparing the specified number of servings of the specified food
(xi) Estimating the number of servings of the specified food that can be prepared using the given quantities of eatable ingredients
(xii) Identifying whether the given steps in a recipe can be carried out in parallel or not with the given eatable ingredients, appliances, number of people available to cook, and utensils
(xiii) Reduce the time needed to execute the given recipe, by identifying the steps that can be executed concurrently
(xiv) Estimating the times needed by the given steps, using the given information about initial state of the ingredients, appliances, utensils, the number of servings needed, and the number of people available to cook

(xv) Finding if the given settings of cooking appliances are correct or not for preparing the specified food, for example, temperature of oven
(xvi) Finding the correct settings of the given cooking appliances for preparing the specified food, for example, temperature of oven
(xvii) Finding the most suitable appliance or utensil for the given step in preparation of the specified food
(xviii) Predicting taste of the product of the given cooking steps
(xix) Predicting the effects of the specified change/changes (for example, increase or decrease in the quantity of an ingredient, skipping a step present in a recipe, executing some or all of the steps in a recipe in a different order, change in cooking method, or change in the time for which the ingredients are kept in oven) on the given feature/features (for example, total cooking time, edibility, appearance, weight, color, calories, fat content, carbohydrate content, amount of fiber, amount of protein, texture, or smell)
(xx) Identifying the food or ingredients, appliances, or utensils used in its preparation, based on the given clues
(xxi) Finding the additional resources needed (number of people, appliances, utensils, or quantities of ingredients) to get the given reduction in the total food-preparation time
(xxii) Identifying changes to the given recipe to achieve the specified objective or honor the specified constraints, for example, a reduction in cooking time, energy bill, fat, calories, carbohydrates, or sodium, or creating a gluten-free version of the food
(xxiii) Finding the minimum number of utensils, ingredients, people, or appliances needed to prepare the specified food in the given time
(xxiv) Finding the number of steps in which the specified ingredient, appliance, or utensil is used in preparation of the specified food
(xxv) Completing a partially-specified recipe by choosing ingredients, appliances, utensils, or actions related to cooking
(xxvi) Challenges about activities taking place between the end of cooking and consumption of food, for example, choosing the most suitable containers for serving the foods prepared, serving the foods in correct order, maintaining smell, temperature, and taste, and arranging the food in correct manner on a plate
(xxvii) Finding all or at least the given number of differences between the given foods or recipes
(xxviii) Finding foods whose preparation meets the given cooking criteria
(xxix) Finding the cooking criteria met by the process/processes of preparation of the specified food/foods
(xxx) Finding steps to correct the solvable problems resulting from an incorrectly-executed recipe
(xxxi) Finding the steps which were incorrectly executed, given the problems with the food prepared
(xxxii) Finding incorrect or irrelevant steps, appliances, utensils, or ingredients present in the given recipe
(xxxiii) Finding ingredients, cooking methods, or their combinations that are interchangeable because of acceptable differences in the versions of the food resulting from the substitution
(xxxiv) Finding steps to modify a correctly-cooked food to meet the specified criteria
(xxxv) Finding a new recipe consistent with the given template
(xxxvi) Ordering the given ingredients, utensils, or appliances based on the number of recipes from the given set of recipes in which they are needed
(xxxvii) Finding the most similar or most dissimilar recipes or foods from the given set

(xxxviii) Clustering the given foods based on the given criterion, for example, putting appetizers, desserts, and entrees in three separate clusters, or putting the foods that can be prepared in 30 or less minutes in one cluster, putting the foods taking longer than 30 min and less than 60 minutes to prepare in second cluster, and putting the foods taking 60 minutes or longer to prepare in the third cluster

(xxxix) Ordering the given foods or recipes according to the given criterion, for example, number of ingredients, cooking time, energy consumption, or number of appliances needed

(xl) Matching the given ingredients, appliances, actions, or utensils with the given foods based on their relevance in the preparation of these foods

(xli) Finding whether the given ingredients, appliances, or utensils are essential in the preparation of the specified food or not

(xlii) Identifying the steps needed in special situations, for example, cooking outdoors when it is windy, extremely hot, or when there are flies

(xliii) Choosing the correct ingredients to use in cooking each day when there are enough ingredients for preparing foods for multiple days, considering the expiration dates, best-by dates, or appearance of ingredients to minimize wastage

(xliv) Combinations of previously-mentioned challenges, for example, cooking a dish from scratch, or cooking multiple dishes

Entertaining, Rewarding, and Motivating the Players

The games can be made entertaining by including animations, sounds, pictures, jokes, stories, and non-playing characters. These can also have the effect of motivating or rewarding the players.

The players can be motivated in many ways, for example, providing bonus ingredients, facts about food, facts about parties, cooking tips from top chefs, information about how much they can save by cooking instead of eating at a restaurant or getting the food delivered or picking it up, inclusion of the player's/players' recipe in the next version of the game or a digital book of recipes, or providing incentives in the real world, including execution of their recipe in the real world by a third party and delivery of real food to people of their choice, invitation to cook at a real restaurant, inclusion of the player's/players' novel recipe in the menu of a restaurant for a certain period, inclusion of the player's/players' novel recipe in a physical recipe book, invitation to a cooking show on television either as a contestant or as a judge or as a host, a share of the revenue obtained from commercialization of the player's/players' recipe/recipes, discounts at grocery stores, restaurants, or discount on health-insurance premium, fees of cooking classes, or membership fee of a gymnasium. These can also be seen as ways to reward the players.

The rewards can be in the form of additional ingredients, additional quantities of ingredients, additional or more efficient utensils or appliances, extra time for cooking, additional people to help in cooking, automatic execution of some steps to help the player, or hints for reducing the difficulty of challenges. These can also have the effect of motivating the players. There are other ways to reward the players, e.g., by providing a bigger or renovated kitchen.

Designing the Levels of Computer Games About Cooking

Different levels can differ based on the types of challenges and/or numbers of challenges. Levels can also be designed based on how people typically learn to cook and apply what they learn. We provide a list of levels next, but other alternatives exist.

Level 1: Testing knowledge of eatable ingredients, appliances, and utensils

Level 2: Choosing suitable ingredients in suitable quantities, and performing suitable operations using suitable utensils or appliances in suitable order to create one food for consumption by one person

Level 3: An augmentation of the challenges in Level 2 because of the player being required to create a multi-course meal

Level 4: An augmentation of Level 2 because of the player being required to cook the food for consumption by multiple people, and hence being required to perform calculations about quantities and servings

Level 5: An augmentation of Level 4 because of the player being required to cook a multi-course meal

Level 6: An augmentation of Level 5 because of the player being required to cook multi-course, multi-cuisine meals

Levels can also be created based on the courses of a multi-course meal. The first level can be for soups, the second level can be for appetizers, the third level can be for salads, the fourth level can be for the main course, and the fifth level can be for desserts. Levels can also be created based on the total food-preparation time. The first level can be for foods taking 15 or fewer minutes to prepare, the second level can be for foods that take more than 15 min but not more than 30 min to prepare, the third level can be for foods that take more than 30 min but not more than 1 h to prepare, and the fourth level can be for foods than take longer than 1 h to prepare. The levels may be based on the types of places serving food. These include food carts, food trucks, food halls, fast-food restaurants, casual-dining restaurants, and fine-dining restaurants. Levels can also be based on occasion. The first level can be about cooking on weekdays. The second level can be about cooking special food on weekends. The third level can be about cooking for family events, including birthday celebrations. The fourth level can be about cooking on public holidays with special foods associated with them, e.g., turkey and Thanksgiving. There can be more than five levels. Additional levels can be created by including additional constraints, by including temporal deadlines, dietary restrictions, limiting the quantities of the ingredients shared by multiple recipes, limiting the number of times a specific utensil or appliance can be used, or constraining the temporal intervals during which the player can access certain ingredients, appliances, utensils, or areas of the cooking world due to others needing these resources for their cooking. There are other ways to make higher levels more complex. Having many challenges in one level may discourage the player because of long time or multiple gaming sessions needed to get to the next level.

Evaluating the Player

In general, a player can get or lose points based on the correctness of choices related to ingredients, appliances, utensils, quantities of ingredients, cooking methods, wastage of ingredients, order of the steps executed during food preparation, total duration of food preparation, or durations of individual steps, and satisfaction of additional requirements, including dietary constraints. The specific scoring method will depend on the challenges presented to the player.

Multiplayer Versions of Computer Games About Cooking

Different players can cooperate or compete. If there are multiple players but no teams, then the players can be ranked based on scores. If multiple players have an equal score, then additional criteria can be used to rank them, for example, the total number of attempts needed before correct choices were made. When teams of players can be formed, a player can have a specific set of roles. For example, one player can be in charge of getting the ingredients ready for cooking, another player can be in charge of mixing the relevant ingredients and carrying out the correct operations in correct order using correct utensils or appliances, and the third player can be in charge of monitoring the entire process and correcting mistakes in a timely manner, when there are three players on a team. The actual distribution of responsibilities among the players depends on the

challenges, their skills, and the levels of these skills. When players compete, core challenges can include getting the right ingredients in right quantity or state, getting access to utensils or appliances, protecting the ingredients or their combinations at various stages to preserve edibility, shape, arrangement, smell, taste, or temperature, and even getting space to work on individual ingredients or their combinations at various stages. Players can lose points for being obstructive or destructive, intentionally or unintentionally, and negatively affecting competing or collaborating players as a result.

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Online Games

▶ Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

Online Gaming Architectures

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Synonyms

Distributed architectures for online multiplayer games; Gaming infrastructures; Multiplayer online gaming architecture; Networked gaming architectures

Definitions

Online gaming architecture refers to the distributed system architecture that is employed to support an online game session with multiple participants, geographically distributed and connected through the Internet.

Networked Multiplayer Games

Networked multiplayer games are contributing to an increasingly large proportion of network traffic (Suznjevic et al. 2013). In order to support massive multiplayer online games, users must be provided with scalable architectures, able to handle a large number of players geographically distributed over the network that play together. This

forces the use of specific solutions, specifically thought for online gaming applications.

Problems of Networked Multiplayer Games

An interesting approach to evaluate the effectiveness of a gaming architecture consists in considering the well-known "Eight Fallacies of Distributed Computing" (Wikipedia 2017). According to Peter Deutsch: "Essentially everyone, when they first build a distributed application, makes the following eight assumptions. All prove to be false in the long run and all cause big trouble and painful learning experiences." In essence, these eight fallacies and assumptions contribute to poor user experiences and must be accounted as fundamental principles during the design of a scalable architecture.

The eight fallacies are:

1. *The network is reliable*. The larger is the number of entities composing the distributed architecture, the more this assumption results false. Thus, sophisticated mechanisms that provide reliability without affecting the interactivity and responsiveness of the game system must be devised.
2. *Latency is zero*. Latency is a main issue in online games. Indeed, high delays and high delay jitters may impair the responsiveness of the system and render the gaming activity a frustrating experience to users.
3. *Bandwidth is infinite*. In wide area networks (and Internet), this assumption is definitively false, due to network congestions and bandwidth bottlenecks.
4. *The network is secure*. This fallacy is common to most distributed systems; in games, cheating-avoidance approaches (Ferretti 2008) and intrusion-prevention mechanisms must be adopted.
5. *Topology doesn't change*. In the Internet, link failures and congestions may result in topology changes that may alter (improve or degrade) transmission delay and jitter. In this sense, cloud computing services now provide new mechanisms to surmount these problems in networked games.
6. *There is one administrator*. Even if in current (centralized) gaming applications this statement can be considered as valid, supporting a large-scale networked game might require a decentralized control of some shared resources.
7. *Transport cost is zero*. In the Internet, users (providers) have costs in order to access (provide) the service.
8. *The network is homogeneous*: This assumption is obviously false. Moreover, the heterogeneity of the network is going to increase now that new mobile technologies offer diverse typologies of network services to customers.

Online Gaming Architectures

In order to support game applications with players geographically distributed and connected to the Internet, several architectural solutions have been presented in the research literature and in commercial products. It is possible to distinguish among the following:

- Client-server architectures
- Peer-to-peer architectures
- Distributed architectures

In essence, an online game architecture is typically composed of two types of entities: client entities (CE) and one or more game state server entities (GSSE). A CE is a client software application that performs input/output with its player and receives/notifies events from/to the GSSE to which it is connected. Stated simply, a CE acts as a viewport to the game state and passes commands issued by its players to the GSSE. Using the terminology derived from the IEEE 1516 "HLA standard" for distributed simulation (IEEE 1516 Standard 2000), a CE may be seen as the owner of one or more virtual entities and is responsible for updating the state (e.g., value) of their attributes (e.g., their position). Moreover,

a CE is also in charge of performing graphic renderings. Instead, a GSSE maintains the game state, or a part of it (Marzolla et al. 2012).

In a client-server architecture, there is a single GSSE, while all gamers execute a CE in their exploited device. In peer-to-peer architectures, each node executes both GSSE and CE functionalities, thus requiring a synchronization mechanism among all GSSEs in order to keep the game state at each GSSE synchronized with others. Distributed architectures are a sort of in-between solution, exploiting a subset of nodes in the architecture acting as GSSE, while the majority of gamers' nodes execute only CE functionalities. This solution aims at distributing (and/or replicating) the task of game state management, while at the same time keeping limited the amount of nodes involved in this task, and thus limiting the workload for the synchronization among these nodes.

In addition to the two mentioned game software entities, to enhance players' experiences, also other ancillary services could be provided in the game environment (Wright and Tischer 2004). While some of these services strictly relate to the game (such as the already mentioned game state management provided by GSSEs), others may have only tangential interest to the game play mechanisms (Okanda and Blair 2004). Summing up, a game architecture should provide support for:

- State Maintenance: GSSEs maintain the game state that is composed of the virtual world representation and of the state of all the involved characters.
- Consistency Maintenance: Due to latency, timing relationships may be distorted in the simulated world causing anomalies and inconsistencies. Thus, functionalities are needed so that players perceive the same evolution of the game.
- Group Management: Not all the players are interested to receive exactly the same messages. Thus, grouping of players and event filtering schemes may be utilized. Grouping and event filtering typically relate to some semantics of the application (e.g., players in the same room receive same events), but they could depend also on the client configurations (e.g., clients with low bandwidth connections or with a low computation capacity may receive less detailed information than clients with high speed connections and a high computational capacity).
- Event Delivery: Each generated event has to be sent to other players, so that each participant to a gaming session perceives the same updates during the game evolution.
- Accounting, Authorization: Before starting the game, an initialization phase is possible where each client configures and negotiates parameters with the GSSE to better enjoy the service. Moreover, these services validate players to play a particular game.
- Cheating Control: Each event generated by a player on the virtual world has to be checked so as to prevent cheating (Ferretti 2008).
- Player Communication: Traditional interpersonal communication mechanisms may enhance the game activity, enabling players to chat, send instant messages, or even interact in audio/video conversations (Wright and Tischer 2004). Nowadays, playing games while interacting with other players is quite popular. In this sense, the current approach of online gamers is to resort to external VoIP-based tools to communicate with their gaming friends. This is probably due to a lack of viable solutions offered by online gaming architectures. Actually, there are plenty of such tools, and while any kind of VoIP tool might work, services exist that are made especially for gamers. Examples of these services are Discord (https://discordapp.com/), TeamSpeak (http://www.teamspeak.com), and Ventrilo (http://www.ventrilo.com/). They enable players installing specific applications on their devices as well as using novel Web-based technologies, e.g., WebRTC.
- Multimedia Resource Distribution: When describing a game architecture, the common approach (in literature) is that of considering the resource download activity as an "offline"

task accomplished before starting the game (Bangun and Beadle 1997). Instead, we believe that multimedia distribution activities will massively come into the future game picture. In fact, the new games that are being developed are very dynamic, with players (and most of all, mobile players) that dynamically retrieve all the needed resources to interact with other players.

Cross-References

- ▶ Client/Server Gaming Architectures
- ▶ Cloud for Gaming
- ▶ Online Gaming Scalability
- ▶ Peer-to-Peer Gaming

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Online Gaming Industry Evolution, Monetization, and Prospects

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Synonyms

Electronic sports; Playing; Recreation; Sporting life; Video games; Web gaming

Definition

Online gaming is basically the playing of a computer game over the web, generally with companions. Web-based games can be played on quite a few gadgets from devoted gaming consoles like PlayStations, Xboxes, and Nintendo Switches, to computers, PCs, and cell phones.

Introduction

The gaming industry is one of the biggest and fastest-growing industries. Millions of people around the world are unboxing and downloading videogames each day making this industry even bigger than the movie and music industry combined (Fig 2). It's pretty incredible how much the gaming industry has evolved throughout the years. From MIT scientists making a first video game in their basement in the 1970s to the race of developing home gaming consoles and computer games in the 1980s and 1990s to the whole new market of online gaming in the 2000s and now mobile gaming and eSports (eSports is a form of sport competition using video games. eSports often takes the form of organized, multiplayer video game competitions, particularly between professional players, individually or as teams.) where fulltime professional gamers attract stadium full of crowd and earn millions of rupees.

According to Al (2019):

- In 2016, a third of the world's population was video gaming which is 2.5 billion people.
- In 2017, about 660 million people were interested in watching people play video games on platforms like Twitch and YouTube.
- In 2018, the whole gaming industry made at least 130 billion dollars.
- The gaming industry is rapidly growing by about 10% per year.

Gaming can no longer be considered as just a hobby and to portray it as a niche market is an understatement. It's a blasting industry with wide space for development. Furthermore, with constant advancement and the starting of more game contributions, we can just imagine a splendid future for the gaming business. The fast ascent of innovation will carry the business to different domains, for example, cloud gaming, VR (computer-generated reality) gaming, and AR gaming.

In an interview with legendary game designer John Newcomer (Newcomer 2015):

> Games have to continue to evolve over their lifetime with a series of updates. In general, the games keep giving the player more things to do. New play modes get added, daily quests. More games have been adding a PvP (player versus player) component.
>
> The game starts out as a single player experience and then it evolves into competing against other players. Then you see more community features added like chat, special events. The whole game feels like a party.

Global Active Gamers

Xbox

Microsoft revealed some important new Xbox stats (Warren 2020):

- Xbox Live has nearly **90 million** monthly active users.
- Xbox Game Pass has more than **ten million** subscribers.
- Project xCloud has 100 s of thousands of active users in preview.

PlayStation Network

First launched in November 2006, PlayStation Network (PSN) is a digital entertainment service associated with Sony's PlayStation series of consoles. It has since been expanded to run on smartphones, tablets, and HD televisions.

As of August 2020 (Gough 2020)

- The network had approximately **113 million** monthly active users.
- A significant increase from the **50 million** users in March 2014.

Evolution of Multiplayer Gaming

Multiplayer is one word for many different meanings. To some it's a way of life, even a path to fame and riches and to others it's a chance to have fun with their close ones.

The history of multi-players is as old as the history of gaming itself. Even as far back as the 1950s, the supposedly game of tennis was meant to be a two-player game.

After a long leap there came a game called "Maze War" in 1971 developed by NASA. Maze was the first real FPS (First-person shooter) game in which two computer screens are connected directly to each other and let two players hunt each other down in a twisty deathmatch. In these early days, this experience was achieved by hooking up serial cables between two machines as the internet was not yet developed.

Internet was introduced in 1991, and as soon as in 1993 DOOM was introduced and its network FPS coding changed the industry. Now players can connect up to four computers using LAN (local area network) to play for fun or competitively. A year later in 1994, an early online gaming matchmaking service was introduced which allowed players to connect over the internet and the blueprint for every multiplayer shooter thereafter was drawn.

DOOM's phenomenal success and excitement in the masses didn't go unnoticed. In 1996, QUAKE released, and the big thing about quake was its multiplayer run from servers. Everyone

connected to one server could find each other and now the player didn't have to enter the IP address (Internet Protocol) to find other players. This was multiplayer made easy. It was such a big hit and a landmark in the history that new-age popular games like CS (Counter-Strike) and OVERWATCH took inspiration from its design and strategy.

In the year 1997 Quake also provided a venue for the first-ever eSports tournament and it was called RED ANNIHILATION and the winner got to drive off in John Carmack's Ferrari 328.

All through the 1990s, first-person shooters ruled the sales, mainstream awareness, and the multiplayer; but as the internet became more household-friendly across the globe, opportunities for developers also broadened and so came MMORPG (Massively multiplayer online game).

Games like "Meridian 59" and "Ultima online" popularized the genre of the fantasy land where gamers could create alter egos and live out second lives as Knights, Farmers, or the ruler of the kingdom. The world populated by real players spread like wildfire but the games like "World Of Warcraft" that came out in 2004 gave the genre place of mainstream title.

On the other hand, as the computers become a household necessity, it gave strategy games great opportunity to flourish. Games like STARCRAFT, which is now a big name in the eSport world and hosts million-dollar prize pool tournaments, were introduced in 1998. It sold 9.5 million copies in the next decade and made its place in South Korea. South Korean TV broadcasted eSports tournaments and that gave the competitive gaming an identity.

In March 1999, "Counter-Strike" was released and by the end of the year, it was one of the biggest things in the gaming industry. CS and Quake 3 both made a pretty big impact as with the internet connection at home now anyone can do multiplayer gaming.

In 2002, DOTA emerged from the mods (A mod is an alteration by players or fans of a video game that changes one or more aspects of a video game, such as how it looks or behaves.) of the old starcraft map and people loved it. In the present date, DOTA is one of the biggest games and a big part of eSports tournaments.

In the year 2016, gamers enjoyed an "ARMA 3" mod so much that by the year 2017 it became PUBG (Player Unknown's battleground), the biggest game in the world. It attracts double the play account of DOTA 2 every day. Usually have over a million players online at any given moment and has sold over 20 million copies so far.

Games and gaming experience have come a long way but this was not possible without the technology involved in gaming. From PCs and consoles to Smartphones are the only reasons we can perform such high-level gaming.

In an interview, John Riccitiello, CEO of Unity Technologies, said:

> The scaling of the industry is driven by technology, so if you go back a decade or two ago, back to 1997 all games were 2D because you couldn't power a 3D game through the CPUs and GPUs weren't . . . It wasn't possible. You Couldn't do online gaming, you couldn't connect to another live player and for the most part, you were strapped to the device parked under your TV or your large desktop PC and that's all is not true any longer. The available computers are up to many millions of fold to the consumer on a global scale, networks work better than ever before and that was 2D became 3D, non-interactive became interactive, and non-social became social and in that there are more players than TV watchers or music listeners on basic and the consequence of that taking advantage of the technology that fueled its growth. Cause when I entered the industry it was much smaller than the music or TV industry but it is much larger than the two of them combined. (Riccitiello 2020)

Evolution of Video Game Console

- In the year 1972, first ever console was launched known as Magnavox Odyssey.
- After seeing the interest in the market about gaming consoles several companies launched several consoles to compete with each other. In the next 18 years, almost 15 different models were launched by all around the globe.
- In the 1990s the competition was at its peak and every major company was trying to break-in.

- In the next 10 years, around 17 different consoles were launched including PlayStation in 1994 and Nintendo 64 in 1996.
- After 6 years, in 2000 PS2 was launched and by this time the console industry was slowing down its speed.
- In 2001, Xbox was launched.
- From 2001 to 2020, only 10 consoles were launched and just a few companies were left in the market to compete. Just four companies, namely PlayStation, Wii, Nintendo, and Xbox, launched their consoles in the last 20 years.

Evolution of Mobile Gaming

Mobiles are smartphones now and they have come a long way from being a small telephone to a superfast and capable computer on your palm. The things one can do with smartphones nowadays are limitless. Mobile games were always welcome, and as the hardware grew more powerful, the developers started taking more interest in the opportunities.

- In the year 1994, Tetris was launched in the Hagenuk MT-200 with a black and white display.
- In 1997, "Snake" was launched in Nokia 2170, and it's still a very integral part of every 90s kid.
- Nokia came out with Snake 2 and Alien Fish Exchange in the year 1999 and 2000, respectively.
- In the year 2001, Sonic the Hedgehog became the first colored mobile game.
- In the next decade, several 2D games were launched ranging from racing to strategy.
- In 2011, Grand Theft Auto 3 came out and it became the first 3D game for the mobile gaming industry.
- In 2011, Mini Militia, and it was the first multiplayer game in which players could connect through LAN and play together. It was a big hit among college students.
- In 2012, Supercell launched Clash of Clans and it became one of the biggest games. COC was the first online multiplayer strategy game for mobile phones.
- In 2013, Asphalt 8 racing game was launched and cruelly challenged graphics provided in mobile phone games.
- After a year of launch, in 2018 PUBG Mobile was launched and it became one of the biggest games to date. PUBG Mobile also organizes several multi-million prize pool tournaments all across the globe and has changed the eSport structure of mobile gaming.
- In 2019, Call of Duty: Mobile was launched with the same idea as of PUBG but was a slow burner.

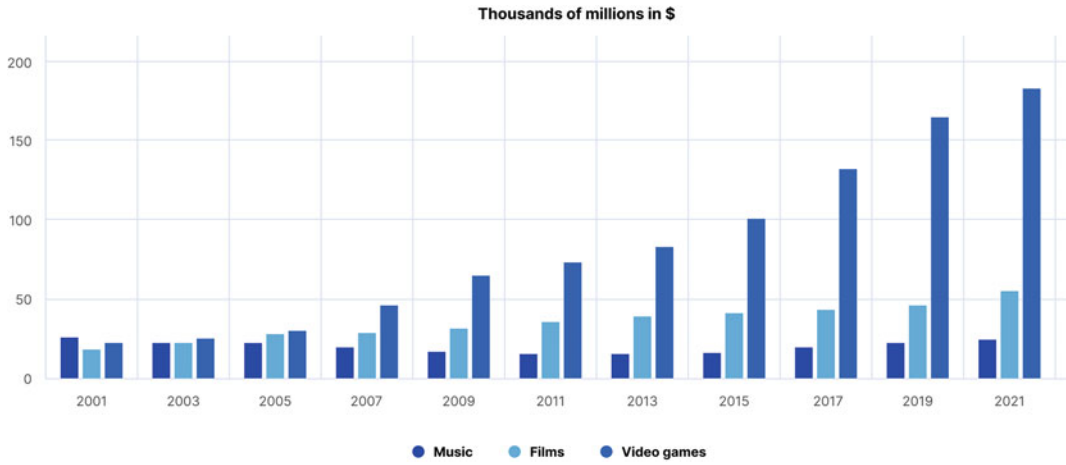
The New Era of Monetization

Today there are 2.4 billion gamers all around the world, and the technologies like blockchain technology (Blockchain is just a record of digital transactions. Blockchain records any transactions made with cryptocurrencies such as bitcoin and Libra) will unlock new opportunities for them to become creators, entrepreneurs, and service providers.

As more and more people around the world are playing in PCs, consoles, and smartphones, more people are looking to break into the industry and make a living doing it. With time gaming companies are also adopting different ways to earn money.

At the turn of the century the gaming market, the global box office, and the music industry were about the same size but over the last 19 years the gaming market has seen immense growth, and as of 2019 the gaming industry is a $150 billion market, it's larger than the music and film industry combined together, and it's been that way for last 8 years and the gap is only growing (Fig. 1).

PC game industry as of now gets more cash-flow versus movies and music industry combined. It's not because more individuals are messing around when contrasted with watching films but because of the imaginative income models that the gaming business has presented over the previous decade.



Online Gaming Industry Evolution, Monetization, and Prospects, Fig. 1 Thousands of millions in $
Source: (Zeeshan 2020)

In-application purchase, in-game promotions, development packs, season pass, restricted version skins/ensembles, and so forth to give some examples. Although film industry income streams separated from the development of OTT stages have essentially been the equivalent.

Fortnite is one of the biggest battle royale games with millions of viewers each day and it's free. This is because of the new model gaming companies have adopted and that is micro-transactions, that are selling things in the game itself. For example, if the person wants to upgrade the look of the avatar or wants to buy skins for the guns or wants to buy an extra life, it is just a small transaction away. Fortnite made about $2 billion dollars in 2018 despite being a free to download game.

So the idea is despite paying for everything upfront, the gamer is now paying in little streams of $1, $5, and $10 to the game company and it turns out the company makes tons more money in that model than they ever did back in the day. This money pouring into a lot of games isn't coming from casual gamers, it is coming from a small group of big spenders known in the industry by a very special name: "Whales."

> A whale is a player that spends a lot and plays a lot. They love this game and they love being powerful and special and the big spenders will drop $2000 to $3000 a month. (Perianez 2018)

Whales make up just a tiny fraction of total players but then can generate more than half of the games' total revenue. This means finding and nurturing a potential whale is the real game.

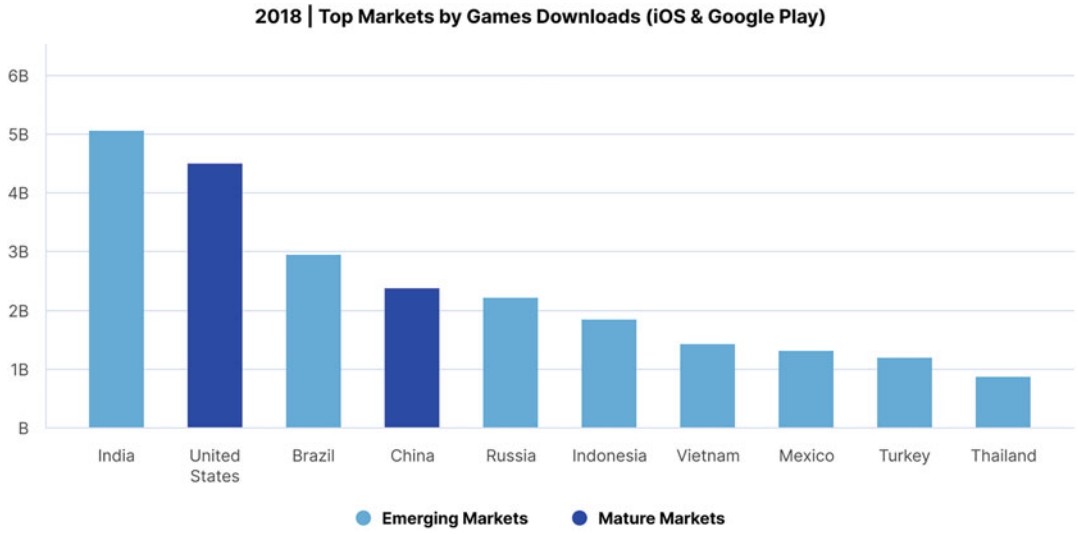
Several big-time business tycoons are now purchasing professional gaming teams and this not only helps in generating revenue from the tournaments and brand deals but also from viewers who are willing to watch the stream and influence other casual gamers to potentially convert into whales.

Computer games as a Sport are additionally a developing pattern wherein future projections show that eSports will be as large as NBA, EPL if not greater. Starting today, eSport competitions are the biggest gaming tournaments that occur.

Games are not only a multi-billion-dollar business but at the same time, it is making a huge cultural difference too. Several movies are being made based on videogames like Prince of Persia, Tomb Raider, and Assassin's Creed. Each movie has done great box office collection and has attracted A-Listed talent like Angelina Jolie, Jake Gyllenhaal, etc. Also several talented and famous actors are more than happy to play a role in the game itself too.

Making Living Out of Gaming

The concept and idea of monetization has completely changed over the years. Traditionally



Online Gaming Industry Evolution, Monetization, and Prospects, Fig. 2 2018 | Top Markets by Games Downloads (iOS & Google Play) **Source:** (Zeeshan 2020)

making a living in the gaming industry was about making games itself. Early on games were often made by a single person and all the money made from the game was up for grab but now the scale is a lot bigger. A large number of development teams to marketing teams give their blood and sweat to develop a game. But now not only developers but gamers are also earning big numbers and people don't even realize or consider it as a career option.

eSport is one of the biggest growing but underrated career options. Kyle Giersdorf, a high school junior at the age of 16 years, qualified for the Fortnite World Cup Finals from a field of 40 million and went on to beat 99 players at Queens' Arthur Ashe Stadium to become the eSports' first solo champion, taking home $3 million in prize money in a 3-day tournament. This is much more than the prize money of any major sports tournament.

And not just this, there are salary opportunities in this too. The average salary for a League of Legends player is about $320k a year and this is only possible because of the enormous viewership. About 99 million people turned-in to watch the championship event, and it was broadcasted in 19 different languages across 30 different platforms including ESPN.

The tickets to these kinds of events sold out within a day and this can very much explain the enthusiasm and motivation of people toward this industry.

Apart from professional tournaments, streaming also contributes to gamer's popularity and revenue. Streaming is where a gamer is playing a videogame and broadcasting it over the internet for anybody to watch via platforms like Twitch and YouTube. Streaming gives the viewer the power to enjoy the game without having the skill part to complete the game. Not just professional gamers but casual gamers are also streaming games, and according to the numbers, people are enjoying it.

Ninja is one of the most famous streamers in the world and through his fan subscriptions also he makes $500k a month, and this is without even including his endorsements deal like his Adidas partnership or such as his appearance fees like hosting Red Bull's new year party at Times Square.

So taking this as an example it is very clear that the monetization method has increased the opportunities all around us.

Today people earn a living in gaming in three ways:

O

1. Develop Game
2. Professional eSports
3. Game Streamer

Even with these new opportunities, the chance to make it into the industry is still incredibly tough. For example League of Legends, there are over 100 million active players in this game today whereas today in the entire world there are just under 1000 professional players and that's 0.001% of the people that can make it to the pro leagues.

On Twitch (Streaming Platform), there are over three million active streamers a month, but of that only 10 thousand are in Twitch's partner program making a full-time income that is 0.33%. So, to think it through before joining and career path is very important.

Conclusion

We can say that gaming is not simple entertainment now. It has become a grand business model with enormous money and status involved. World level industrial houses are entering in gaming industry and applying all possible strategies to face cut-throat competition.

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Online Gaming Scalability

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Synonyms

Game performance

Definitions

Online gaming scalability refers to all those techniques that aim at supporting online game sessions with a variable amount of participants. No matter the amount of players, the online game session must provide a fluid, compelling, and responsive game evolution.

Scalability Issues

Today, almost all games have some online components that enable users interacting in an online game session. The high demand for such online services poses several scalability issues. The service must provide enough capacity to handle all requests and scale with the number of players they need to serve. In general, scalability indicates the capability of a system to maintain its performance under an increased load (Jogalekar and Woodside 2000). The demand for scalability is an issue common to all distributed systems and applications. Online games do have such need as well, which is complicated by the fact that at the same time, a high level of responsiveness must be

maintained, in order to provide a compelling gaming experience to all the players.

There are different possible approaches to manage a high amount of players: a solution is to increase the resources devoted to handle the application; then, it is possible to reduce the amount of interacting entities; finally, it is possible to reduce the communication required to handle the game state evolution.

Increasing the Resources

The idea of this approach is quite intuitive: the more players are playing the game simultaneously, the more resources are needed to handle the game state and the interactions among players. This approach is the common one used in every type of online client-/server-based application, i.e., as soon as the amount of clients increases, the service provider needs a more powerful server.

The server must be able to manage the user requests during the peaks. Overprovisioning the server might be a solution. However, when there is a lower amount of players wanting to play, this solution wastes capacity. For instance, this might happen at night, when most players are not playing; thus big parts of the server are idle.

The advent of cloud computing solves this issue. This architectural approach provides the combined computation and storage resources of an undetermined number of machines to other devices at arbitrary locations on demand. Resources can be added or removed on demand, based on the amount of users. This is the most used architectural approach to support current online games (Marzolla et al. 2012).

Partitioning Techniques

Partitioning techniques are an alternative approach that is typically combined with the use of multiple server resources, so as to increase scalability. The idea is that if there are too many players willing to play a game, it is possible to instantiate multiple servers and distribute the player across these multiple instances.

In some cases, the servers are mirrored, and they manage the same game state evolution. This architectural solution benefits from the partitioning of the players across multiple servers; however, servers must synchronize their game state updates in order to guarantee a consistent and correct evolution of the game state (Palazzi et al. 2006).

In other cases, the server instances are set independent from each other. Each server has its own game session which has nothing to do with others running on other servers. As an example, imagine a large virtual world that is partitioned into different regions, and each server is responsible for a given region. Another example is that each server is responsible to manage a different game session, involving a specific subset of players. For instance, think at a sport game session with a limited amount of involved players. In order to make sure that players are distributed evenly across all servers, different load balancing strategies can be used.

Communication Reduction Mechanisms

The many entities (e.g., avatars, non-player-characters, environment) participating in an online game need to interact for exchanging data. For example, the position of each avatar in the virtual world must be timely updated. This data is often encapsulated in the form of messages. A simplistic solution to this problem is to broadcast all the relevant messages to all entities in the online game. The main drawback of this approach is its (lack of) scalability. As a solution, many communication reduction mechanisms have been proposed; among them two main approaches can be identified:

- **Filtering of interactions** based on their relevance (i.e., interest management, spheres of influence, data distribution management)
- **Frequency reduction of the interactions** (i.e., dead reckoning)

In both cases, the goal is to minimize the number of exchanged messages among nodes involved in the online game.

Interest Management

Interest management (Morse et al. 2006) is a technique based on interest expressions (IEs) that are used for implementing a filtering mechanism. The IE is usually based on location (or other application-specific) attributes and provides a way for each entity in the game to receive only the subset of information that is relevant for it. The information that is relevant for an entity is often referred to as its domain of interest (DOI).

In the years, many interest management schemes have been proposed with different communication models and filtering mechanisms. The aim of all such techniques is to reduce the number of messages that is transmitted over the network. This is accomplished by specifying in each receiver what type or class of messages is interested to. For example, an entity shall be interested in all the messages that are correlated to its sensing capabilities. This is called aura and it is modelled as a subspace in which the interactions between the entities occur. More specifically, the aura can be defined using different methods such as formulae, cells, polygons or extents. In case of mobile entities (such as avatars associated to a player in a game), their aura needs to be updated during the entities' movement. This aspect can introduce a relevant overhead in the interest management implementation.

An interest management implementation can be found in the high-level architecture (HLA) specification (IEEE 1516 Standard 2000). The so-called data distribution management (DDM) is responsible to manage the areas of interest in distributed simulations that are compliant with this standard. More in detail, the DDM services are responsible for sending events generated on update regions to a set of subscription regions. Each event in the simulation can publish data in specific update regions and subscribe to the events that are published in the subscription regions.

A different formalization of the interest management is called *spheres of influence* (Logan and Theodoropoulos 2001). In this case, it is assumed that different types of events have different spheres of influence within the shared state of the online game. The term "sphere" is used metaphorically and refers to the parts of the shared state that are directly affected by a specific instance of a given event type. Considering the spheres of influence, it is possible to filter the delivered messages but also allocate the entities composing the online game on the different parts of the execution architecture with the aim to reduce the amount of communication.

Dead Reckoning

The aim of dead reckoning techniques is to reduce the frequency of updates that need to be delivered to the entities in an online game, for example, the position of each avatar in the game environment (Wolf and Pantel 2002). Dead reckoning consists in estimating an avatar's current position based on a known starting point and its velocity. The basic idea is that using both the starting coordinates and velocity, it is possible to predict the position of the avatar with a given level of confidence. In this way, it is possible to reduce and delay the transmission of next messages embodying position updates. This permits to reduce the network traffic and to save the communication latency at the cost of (some level of) data consistency. The presence of data inconsistencies introduced by the dead reckoning mechanisms must be addressed each time a new update message is received. For example, unexpected jumps in the position of entities must be avoided using appropriate "smoothing" techniques.

Cross-References

- ▶ Client/Server Gaming Architectures
- ▶ Cloud for Gaming
- ▶ Peer-to-Peer Gaming

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Online Players: Engagement, Immersion, and Absorption Across Secondary Worlds

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Synonyms

Gamers

Definition

Online players are players engaged in online gaming. They participate in a kind of games that are largely based on social interaction as their main form of play. Online players vicariously enter and interact with secondary worlds, their elements, inhabitants, and stories. Through their choices and activities, players affect the happenings occurring in such settings: they are in charge of taking action and making choices to make the game progress.

Secondary Worlds: Extra-Ordinary Spaces

Games can be framed as systems where players struggle against their fates, moving in a meaningful space of conflict with an uncertain outcome. If this definition describes games in general, it is not sufficient to explain the deepness reached by online games set in secondary worlds. They go further, engaging online players in challenging processes of immersion and absorption within persistent, evolving worlds where everything is deeply intertwingled.

Relying on the game studies literature, games are archetypically thought of as closed systems that bring to a form of activity, playing, that is timely, spatially, and socially separate from the everyday life and world. Since game-playing stands outside ordinary life, in the field it is typical to use the metaphor of the *magic circle* (Huizinga 1938). This concept conventionally identifies that *other space* where players operate, following specific formal rules. However, especially in the last decades, the borders of this definition have been pushed – and questioned by several authors. (The metaphorical idea of a magic circle was first introduced by Huizinga (1938), then reframed by Roger (1958) and later formalized by Salen and Zimmerman (2004) who contributed to its extensive dissemination. This article acknowledges both the critics (Taylor 2006; Malaby 2007; Consalvo 2009) and the defences (Zimmerman 2012; Stenros 2014) moved to the concept. Their discussion, although related, goes beyond the scope of this paper.).

From exponential computing power to the speed of our broadband connections, we are indeed living in years of ongoing technological transformation that is pressingly affecting the digital gaming field and the way players play, and the online gaming provides a clear mirror of such changes. From being a minor fraction within the broader business of interactive entertainment, online gaming flourished, turning into a major

market itself. According to the ESA Annual Report 2017, "53% of the most frequent gamers play multiplayer games, at least once a week, spending an average of 6 hours playing with others online." (data from the *2017 Essential Facts About the Computer and Video Game Industry* released by the Entertainment Software Association in April 2017). In parallel, significant efforts concern the development in terms of maintenance and expansion of the so-called *persistent worlds*, revealing a paramount attention towards massive multiplayer online games. (Fictional worlds that continue (or also simulate to continue) to exist and develop even when their players are not interacting with them (Bartle 2004). The term originally refers to virtual worlds, but is frequently used in relation to online fictional worlds (Adams 2010) as the ones of massively multiplayer online role-playing games and also pervasive games. Examples are: *World of Warcraft, Guild Wars, Destiny*, *Animal Crossing*.) And if games have indeed changed over time, with them it also changed players, the way of playing, and the culture of playing itself.

If the term online games generally refers to a technology rather than a genre per se, it is also true that connecting players together allowing multiplayer distributed games fed new ways of playing, foremost based on online social interaction as leading mechanic. Online games extended their gamespace, and hence players' gamespace: deeper and more interactive scenarios with growing agency in the players' hands, extended worlds to explore, where time is irreversible, distributed communities and people always available to play, 24/7. Unlike older media, these contemporary ways of playing keep asking players to enter the *liminal space* (Turner 1982), but also to transgress former boundaries. In doing so, screens and controllers assume the function of threshold objects (Murray 1997, 108) that welcome players to the realm of escapism and entertainment.

Matter-of-factly, addressing the topic of online players implies covering a substantial amount of topics. Tapping into the twists and turns of what it means playing online, the reasoning that follows takes the player's perspective and unfolds among the concepts of secondary world and its features, immersion, absorption, and their implications, socialization, and sense of belonging to dislocated but unified communities.

To unravel the knot, it is necessary to start from the foundations, and therefore outline the context wherein players move and explore its features. *Secondary worlds* is Tolkien's way of referring to those fictional, imaginary worlds that constitute the settings where stories can take place (Tolkien 1947). Albeit differing from the actual, real world – also called primary world – secondary worlds are self-consistent places with their own, unified sense (Wolf 2012). Regardless of their dimension that can range from being as small as an isolated village, or as big as a whole universe, these worlds have their own events and elements, characters and rules, duly intertwined and intermingled. Even if they are not "physical," secondary worlds are a significant matter to those players who engage and commit to them. They extend far beyond being mere game settings. To some players, certain fictional worlds become so stirring and engaging to appear "more real than reality itself." They are dynamic, complex models able to evolve and expand over time, engaging players in grasping their embedded and constitutive meanings. Indeed, their role is as key to sustain the fictional characters that live in these worlds and maintain their stories coherent, as much it is relevant to players, who can move and make experiences within those sound and consistent spaces.

In spite of being passive observers, indeed, online players are empowered to vicariously enter and interact with these worlds, their elements, inhabitants – NPCs behaving intelligently (artificial intelligence) and/or other online players (human intelligence) – and stories, affecting with their own choices and activities the happenings occurring in such settings. Taking the distance from traditional media, games as simulations (Murray 1997) recognize players' active role (Adams 2010; Lebowitz and Klug 2011): players participate in interactive representations (Frasca 2003) where they are in charge of taking action and making choices to make the game progress.

If in single-player online games the emotional engagement is mainly due to the meaningful

interaction with the narrative, the gameplay, or an holistic, balanced combination of the two of them, in multiplayer online games the engagement comes to a great extent from the interaction with the environment itself, as well as with other players, from the overall conflict and the competition against the others, and from the awareness of being part of a broader community actively committed to that world. These social activities, further expanded in the following, bring to relevant implications that are additional source of engagement, feeding sense of fulfilment and gratification (McGonigal 2011). Indeed, the formal structure of online words offers a large amount of quests and adventures, and affects the traditional use of game stories and of the narrative arch (Campbell 1949; Ryan 2009) typical of single-player games.

Hence, what is the typology of engagement players experience and seek when playing online games? So far, the rumination just tickled some of the points that make online games compelling forms of engagement.

From Immersion to Absorption: Being in *Another World*

Starting from the premise that human brain is "programmed to tune into stories with an intensity that can obliterate the world around us" (Murray 1997, 98), and discussing the unique properties and pleasures of digital environments, Murray (1997) introduces a concept that is as popular as "thick": that of *immersion*. It is the status of *suspension of disbelief* that occurs when the participation in a world reaches such a level of pleasure and intensity that the viewer/user/player gets transported – or submerged, to persist with the liquid metaphor – in the story, obliterating the outside world from her awareness. (The concept that originally addressed fictional representations (Murray 1997, 98) has later been proven to be valid for both fictional and nonfictional narrative texts (Ryan 2001, 93).) However, this does not mean that the player is rejecting the reality. Remaining conscious of indulging in a game of make-believe (Walton 1990), the attention is simply drawn to a secondary world that surrounds the player and taking over her. As a matter of fact, human beings can pay their attention in a limited way: focusing on one thing brings to pay less attention to something else (Holland 2009, 48; Wolf 2012). It means that while concentrating on the secondary world (its play or its story), less energy is available for focusing on the rest, namely the primary world. The player feels aligned with the story that is unfolding on the screen with such an intensity to outdo the surrounding world (Murray 1997). Hence, the more the player is into the secondary world and into the flow of its events (Csikszentmihalyi 1975, 1991), the less she is into the primary, real one; in consequence, the more captivating and overwhelming her experience of the *other* space becomes. As such, immersion is grounded on a simulative process, mental simulation (Currie and Ravenscroft 2002; Anolli and Mantovani 2011), that is also behind players' identification and projection in other roles (Gee 2003).

At this point, it is possible to assert that the edge is sharp, but there is no contradiction in saying that players get deeply immersed into another world, while retaining awareness of their surroundings. However, the reasoning goes further. McMahan (2003, 68) discerns between two different levels of involvement: at a diegetic level, it draws the player's condition of being "caught up" in the story of the game's fictional world; at a nondiegetic level it describes the intense interest of the player towards the game and its strategies. This reasoning provides room for investigating an additional concept that, digging into level of engagement, goes beyond immersion: that of *absorption*. Wolf (2012, 49) proposes an additional meaning to the word that is usually employed as a synonym of immersion itself, arguing that the concept of absorption differs from the previous because it is a two-way process. The one of *being absorbed*, or "pulled into" a world, and the one of *absorbing the world* itself, and being able to recall it when desired. The first process mainly relies on what discussed unpacking immersion; while the "way back" refers to the player's ability to "absorb" – and "grock" – the secondary world, "bringing it into mind, learning

or recalling its places, characters, events, and so on, constructing the world within the imagination the same way that that memory brings forth people, events, and objects when their name are mentioned" (Wolf 2012, 49). The paramount implication of this activity is that players, in doing so, not only extend the gamespace, but they also embed it, as part of their knowledge. And speaking of online games, the gamespace is often broader and richer than expected. Hence, playing their favorite online games, online players end up with gaining extended and often very detailed knowledge of secondary worlds.

Sociality, Community, and Epic Experiences

So far, the reasoning focused on the way online players relate to the secondary world from a theoretical perspective, rather than covering a topic that once again makes evident how these games blur the borders of the magic circle: player socialization as social expansion. The dynamics that characterize online games are rooted in their own social ecology. Mastery and exchange of knowledge are indeed conventions in gaming culture, and they are structured on the fundamental drivers of status, identity, and affiliation to a group. These drivers define interpersonal relations both within games and while interacting with other players as part of communities.

Player socialization is indeed a distinguishing trait of online games, and harnesses the human tendency to group and communicate. By their own nature, these games encourage social contact. Offering constant opportunities for social interaction, they promote the formation of social groupings, and in so doing they enhance the players' enjoyment of the experience. Far from creating single-player experiences, where every player is in a vacuum, multiplayer online games deliberately foster the gathering into self-organized or established groups, as teams, clans, or guilds (Herz 2002). To enhance the socialization as well as the exchange of information, online games usually present systems for real-time communication, depending on the game, online players can socialize via chat, voice or (less common) video chat systems.

As said, online games do not rest. They are always active, and as such are their players. In consequence, at every hour of the day, networks of individuals connected online cross geographical constrains and interact to play together.

Sociality also takes the shape of community. Communities are an undisputed, vibrant part of online game culture. It is well known that, from an anthropological perspective, playing feeds and elicits sense of belonging (Huizinga 1938). However, online games extend the sense of common identity. Moved by the presence of mutual, shared goals, and harnessing their rich knowledge, experience, tactical skills, and problem solving abilities, online players often participate in experiences that are *epic*. The term is one of the paramount concepts in gaming culture, being key in making game experiences as memorable and gratifying to provoke "shivers down the spine" (McGonigal 2011, 99). A working definition of epic is overcoming the limit of the ordinary to get to the extra-ordinary, "in size, scale and intensity" (McGonigal 2011, 98). Being part of *something epic* means contributing to something larger than themselves. McGonigal identifies three key ways in which games can be epic: creating epic context for actions, epic environments to explore, or epic projects. In each case, online players need to cooperate and carry out their efforts to achieve something otherwise unachievable – an example is *Halo*, and the collective efforts run by its online players.

As said, social interactions extend beyond grouping to take part in a game session. Spurred by common needs as self-identification, sense of belonging to a group that shares the same interests and passions, online players actively engage into virtual community. It is indeed common for players spending time and energy on system where they post, comment, feed discussions, share information and collaborate, as blogs, boards, or forums, in order to contribute and increase the knowledge of their community, the community of players.

A further form in which productive players show their being an engaged community is their active participation in building games themselves, from testing for bugs to creating new contents (Taylor 2007, 113). This attitude underlines a new ambiguity in the field, since it blurs line between creator and consumer.

Cross-References

- ▶ Engagement
- ▶ Experience
- ▶ Immersion
- ▶ Interaction
- ▶ Sociality of Digital Games

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Online World

► Virtual World, a Definition Incorporating Distributed Computing and Instances

Open Source 3D Printing, History of

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Synonyms

Additive Manufacturing; Fused Filament Fabrication (FFF); Rapid Manufacturing; Rapid Prototyping; Solid-Free Form Technology

Definitions

3D Printing is a form of manufacturing that adds small layers of materials together to form an object. This is in direct contrast to subtractive manufacturing, which cuts away at a material to form an object. Open source innovations have lowered the price of machinery and increased innovation in new markets.

Introduction

The market for 3D Printing has an open source variation, which began with the sharing of open designs, and further increased after key patents expired for the original technology. This entry goes through the open source innovations that have occurred since the first step in 2004 with the RepRap (Replicating Rapid-Prototyper) project. Since then, larger industry players and the DIY market has thrived as more have turned towards this technology.

While many are under the impression that the 3D printing spontaneously appeared onto the market around the mid-2000s, there is actually a deep history present that weaves together almost 30 years-worth of innovation, tinkering, and daydreams about the future. There were many emerging companies around the late 1980s, 1990s, and early 2000s within the 3D printing industry. With the origin of these innovations coming from countries such as Japan, France, Germany, and the USA, a surge of interest in a field then known as "Rapid Prototyping" got its start around 1984.

The inspirations and personal stories of the origins of the 3D printing industry are best served for another time. For the focus of this piece, we are going to zero in on the early 2000s where a form of open source 3D printing took hold.

To better understand this, it should be known that there are two major aspects to the 3D printing market. First, there is the high-end manufacturing spectrum of machines. These are high value, high quality machines typically utilized in a variety of large-scale industries such as aerospace, automotive, medical, manufacturing, and research facilities. These are machines created by some of the key originators of the technology, companies such as Stratasys or 3D Systems.

Second, there is the regular consumer market and the DIY market, which may not require the same level of functionality or quality to their prints. This second market has been largely driven by regular home consumer's demand for cheaper printers, primarily provided by the open source 3D printing movement. This does not mean that there isn't interest in the highest quality, it is just more often that it is not the highest priority.

The Open Source 3D Printing Movement Breaks Out

The Open Source 3D printing movement began to grow in the wake of open source designs.

Additionally, prices dropped further when key patents began to expire. Before these market innovations, machines previously cost up to $30,000 for what was considered a cheaper model. After the introduction of these designs, the prices were brought down to approximately $500. The most ubiquitous household name associated with the Open Source 3D printing movement is MakerBot. MakerBot can be thought of as the Kleenex of the 3D printing world (About n.d.). To be more specific, it is a name synonymous with the product but is not the only one. This is similar to when facial tissues are referred to generally as Kleenex when that is actually a brand name. These machines were originally based on open source designs and its rise has been ripe with controversy, as you will soon learn. However, this portion of the market and MakerBot itself stands on the shoulders of an unexpected project. Adrian Bowyer, a British Mathematician and Engineer, is credited with beginning the open source 3D printing movement. Previously studying geometric modeling and computation, Adrian Bowyer was one of the creators of the Bowyer-Watson algorithm for Voronoi diagrams. He also studied Biomimetics in self-copying and self-assembly engineering and smart hydrophilic-polymer gels using affinity interactions for the Department of Mechanical Engineering at Bath University. Dr. Bowyer conceived of the "RepRap" concept as an open source, self-replicating 3D printer as early as 2004 during his tenure (Dr Adrian Bowyer n.d.). After facing his own reluctance, he was pushed by his academic peers to pursue the idea.

RepRap stands for Replicating Rapid-Prototyper. The printer is configured so that it can properly duplicate most of the parts needed for another 3D printer, making 50% of its own parts as early as 2005, and when nuts and bolts are excluded it has recently been pushing 70% (All3DP 2016; About n.d.). Plans exist so that the future versions of the machine will even be able to inlay its own electric circuitry, making the project closer to the goal of a printer that can truly replicate itself (About n.d.). In 2009, using interchangeable heads, the RepRap 3D printer took steps towards that goal and began to make circuit boards with its utilization of plastic and conductive solder. Until machine capabilities evolve, the other parts necessary for total completion are chosen to be cheaply available in most places. Currently, Dr. Bowyer is retired from his tenure at the University of Bath but still heads the RepRap Ltd., which pursues further research surrounding the RepRap project.

These printers have gone through iterations named after people like Darwin, Mendel, and Huxley. Each of the machines were named after famous evolutionary biologists since the project is about replication and evolution (The Official History of the RepRap Project 2016). During their creation, some machines were even recognized for their uniqueness. The shape of the Mendel printer resembles a triangular prism rather than a traditional cube and received the Kartik M. Gada Humanitarian Innovation Prize from the Foresight Institute in 2010. It was also one of the first printers to integrate expiring technological patents within 3D printing.

The initial project has evolved and splintered off into many different areas. With different types of RepRap machines designed for different tasks, such as being able to switch between multiple colors, accommodate large-sized prints, been fitted into suitcases for portability, and has even spawned original concepts like the RecycleBot. The RecycleBot is a machine that turns plastic waste into usable filaments for 3D printers. Surely not the last of what this project inspires, the innovation left in its wake is admirable and is not even the most well-known.

The Most Famous RepRap

To understand the most famous RepRap machine, we will need to look at the company familiar to many as MakerBot. Winding the clock back to 2009, we find that the Cupcake CNC was introduced, or what will become to be known as the first MakerBot printer. These printers soon began to pop up among hacker and makerspaces, marking the rise of a company that would take a tragic comedy turn of events turning it from a darling of the open source world to scorned outsider in less

than 5 years. The rising popularity of the machines brought millions of dollars in venture capital funding, and with it competition.

After MakerBot enjoyed market dominance for a few years, a 3D printer called the TangiBot was released on Kickstarter in late 2012 and deemed a threat to the future of MakerBot, as the designs were essentially an improved design of their open sourced model (Benchoff 2016). Consequently, a month after the introduction of the TangiBot, the MakerBot 2 was released in 2012 and was markedly closed source. Open source champions that helped to found the company in early 2009, like Zachary Smith (AKA Hoeken), parted ways with the company following the break in their ideology. Previously being a creator of the RepRap Darwin 3D printer, he wrote a stanch blog entry and described the move as the ultimate betrayal. In the post, he describes how he is now even ashamed to have his name associated with the product (Smith 2012).

The hollow corporatization of the company continued and in 2013, Stratasys announced it would purchase MakerBot. Creating an ironic full circle of ideas, as Stratasys was actually the originator of the Fused Deposition Modeling (FDM) technology that the original open source RepRap and MakerBot systems were based on – called FreeForm Fabrication (FFF) in their open source counterparts. There was never a return to the glory for the brand, however, and over the last few years MakerBot sales slowly diminished and stagnated. Selling roughly 40,000 printers a year until 2015, where it dropped to approximately 18,000, and only 1421 in 2016 (Benchoff 2016). This could also be attributed the massive market saturation encountered, as even the professional version of RepRap, called RepRapPro, also shuttered its doors.

The MakerBot brand has struggled since and faced downsizing in terms of employees and locations, eventually closing all and outsourcing manufacturing to China. This reaction was partly viewed as the distaste left in the mouths of consumers knowing the origins of MakerBot, but mostly systematic errors on Stratasys's part in the creation of a "Smart Extruder" that was anything but. These miscalculations eventually led to a class action suit against Stratasys where investors state that the fifth generation of the printers were rushed, generated negative feedback, used misleading positive claims, caused numerous warranty claims, and returns of the product (Benchoff 2016). It was also an ill hand to play at the time as the market had become saturated in recent years with cheaper printers that were being created and funded on sites like Kickstarter at a rapid pace.

This was not the only controversy to daunt the company. MakerBot was also behind "Thingiverse," a website repository for 3D printer designs that was mutually accessible by everyone. The site flourished and many people turned to utilize it; however, under the leadership of Stratasys eerily similar applications for patents were filed that seemed to be based on designs uploaded onto the site. This created a row among creators and content managers, alongside denting the image of the platform. While Thingiverse is still going strong, platforms like YouMagine gained traction and steam through the ensuing conflict.

This fall from grace does not mean that there is not viability in the open source 3D printing movement, or even redemption. MakerBot has offered an experimental platform for users to interact with in 2017 for free, though it will never make a full return to its open source roots (Orf 2017).

It is important to note that the RepRap project opened the world of 3D printing up, enabled MakerBot to even have a beginning, and through its pursuits and influence enabled the desktop 3D printer to come to roost in many homes across the world.

Continuing the Drive of Innovation

The passion for this liberation of knowledge is no longer restricted to smaller companies or groups

of individuals seeking to create accessible knowledge for the masses. For example, Autodesk is a leader when it comes to many high end software used by gaming, animation, and many other industries. They are a software company that has turned hardware developer and has dedicated aspects of its core products to open source. The product is their Ember line of printers. They have even released the formulas for their resins.

The machine schematics and parts lists were shared under the Creative Commons Attribution ShareAlike license. The firmware was shared with a GNU GPL license. The printer is a Digital Light Processing (DLP) style printer, which makes it unique as most open source designs are FDM/FFF, as with RepRap. What Autodesk realized was that publishing the source files, parts list, and resin formulas for its product does not have to interfere with its ability to be profitable. The head of Autodesk's hardware group said:

> We're open sourcing our resin for a couple of reasons: We have an open approach, and encourage the use of 3rd-party materials in our printer... Autodesk is thinking differently about 3D printing, and sharing under a license reflects our commitment. Open sourcing our resin formulation is only the first step in the journey of opening our 3D printer and our Spark 3D printing platform. (Hurley 2015)

These examples of open source 3D printing technology do not capture the full scope that is represented. There are influential companies such as Lulzbot or the high-end Ultimaker that have carved out their own market niches. Countless projects on platforms like Kickstarter and projects created in garages around the world continue to change the face of this movement. There is more innovation waiting and the field is chipping away at other forms of popular 3D printing technology, especially as other key patents expire in other domains in 3D printing. It is important to note that there cannot be an expectation that another explosion of innovation such as what was viewed with the FDM technologies will occur again. The unique dynamics that attributed to the rapid onslaught of innovation for that style of printer will be hard to replicate. These are things such a few patents to overcome, simplistic design, a hungry market, and lower costs of entry and design.

Conclusion

There should be little doubt that the open source movement will continue to create innovations in its wake, while producing better products in the competition that it spawns. There is hope that 3D printing in the hands of the masses will create a better, stronger, more reliable technology as it becomes more mainstream and integral in our lives.

The economic, social, and societal impact could also be greatly underestimated. Let's look at a comparable technology. When computers were first invented they were hulking machines, taking up entire rooms, required punch cards, and held no graphically based user interface for most of its existence. The graphical interface and an underlying way to interact with the technology is important in the usability of computers and what attributes to its wide adoption. It has only been since the late 1970s and 1980s that these machines found there a way to the more common user. This step many years ago opened up a niche and has forever changed our economy, society, and world.

There is a similar path at play here. The time frame is still murky, but within the next few decades, the dismay that some currently show towards the potential of 3D printers will seem inconceivable. The software and ease of use are going to continue to evolve and bring more usability to these machines. Lessening the costs of these machines enables more research, faster development and overturn of prototypes, and the ability to learn as never before. The impact of this type of movement cannot be understated, and its fruition will be exciting to see.

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▶ Open Source 3D Printing, History of

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Open-Ended Problem-Based Learning

► Challenge-Based Learning in a Serious Global Game

Open-World Game

► Animal Crossing: New Horizons and Its Popularity During COVID-19 Pandemic

► Legend of Zelda Breath of the Wild and the Lens of Curiosity

Organic Music

► Adaptive Music

Origin of Games

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Definition

Games are rule-based interactions. In the popular use – and for literally thousands of years – the term refers to playful activity. *Computer games* are all games that are played using a computer to display the board, generate events, provide other players to play with or, generally, for any other game relevant aspect.

Introduction

Playing and games are an essential part of human behavior, with a plethora of positive effects on the social and cognitive development of individuals.

Games have been played since the dawn of human civilization, and some have persisted through the most dramatic changes in society and environment. Games are seen to serve a range of purposes and have been described as being an integral part of society (Bell 1979), of teaching (Hildmann and Hirsch 2008; Smaldone et al. 2016), learning (Hildmann and Hildmann 2009a), and growing up (Miller et al. 2010).

The history of games easily fills entire books and a number of such books offer a detailed account, e.g., Tylor (1879); Murray (1952); Bell (1979); Miller et al. (2010), to name but a few. We know that games have been played for thousands of years (MacKenzie et al. 2004; Murray 1952), and – depending on your definition of what a game is – we can argue that they have been around for as long as we have recorded history. Computer games, in contrast, have only recently entered our culture (Hildmann and Hildmann 2012a, b), but their impact has been massive (cf. Jahn-Sudmann and Stockmann 2008). The rapid growth of

literature on computer games (e.g., Dillon 2016; Fox 2013) speaks to their continuously growing relevance.

Practitioners have argued for decades that games are – and that the playing of games is – culturally significant (Sutton-Smith 1986; Mechling 1987). As far as computer games (and the computer game industry) are concerned, they are by many considered an essential part of the software and entertainment industry (Saarikoski and Suominen 2009). Here we discuss the terminology of "game" and "play," the benefits of playing and the origins of games which brings us to the first computer games.

Play "n" Games

In the English language, games are "played," rather than "done" or "conducted" – yet play is a much wider concept than merely extending to games. In this entry, we will see the term "play" generally applicable to games, while emphasizing that playful behavior and experience is a continuum, and computer games and others can vary greatly between being highly engaging and joyful and being a dull training exercise thinly disguised by the label of "games."

The use of games for nonrecreational purposes, often referred to as *serious games*, is certainly not new and certainly not restricted to education (Puschel et al. 2010); *business games* have been proposed for research as early as the 1960s (Babb et al. 1966) and 1970s (Rowland and Gardner 1971). Games have been used to great success to train complex problem management (Pasin and Giroux 2011) problem solving abilities (Christoph 2006) as well as practical and reasoning skills (Pee 2011).

As discussed extensively in Hildmann (2013), games are also used as embodiment for psychological experiments (e.g., Rutledge et al. 2016). In fact, (computer) games themselves have been analyzed from a variety of perspectives, both negative (e.g., aggression, violence, or gender stereotyping) and positive (e.g., skills development, engagement, or motivation) (Connolly et al. 2008). Poorly devised educational games run a high risk of failing their intended purposes, especially when not taking the players' views and likes into consideration run a high risk of failing their intended purposes. Games in the context of this chapter are verbal, physical and/or virtual interactions governed by a set of rules between participants, i.e., *players* – or between a player and the environment – for the purpose of experiencing flow (Csikszentmihalyi 2009) and/or positive emotions.

Playing as an Essential Human Activity

Playing is an urge and activity inherent to humans – and other species (Bjorklund and Gardiner 2011; Pellis and Pellis 2011; Smith 2010). This suggests play to have a significant value for the individual development and evolutionary survival of those engaging in it. And indeed, a wealth of literature discusses the benefits perceived gained from participating in games and play.

In the literature, such as Pellegrini and Smith (2005) or Smith (2010), it is generally agreed on that different types of play are distinguished:

- *Object (manipulation), sensorimotor,* or *functional play* (such as e.g., shaking a rattle, building a tower with bricks) is shown to improve neurosensory maturation, body coordination, and mental representation of objects (Smith 2010).
- *Social contingency play* (Smith 2010).
- *Locomotor play* or *physical activity play* (e.g., running, chasing, swinging, pretending to be a superhero in action) is argued to support physical development of children, cognitive performance, and social organization (Pellegrini 2011).
- *Pretend* or *fantasy play* (e.g., moving wood blocks around like cars or planes, playing "mother-father-child" or "doctor and patient") exercises social patterns or "scripts," language and other cognitive skills, role-taking, and creative imagination (Smith 2010; Kavanaugh 2011).

- Physical activity play (e.g., rhythmic stereotypes/repetitive movements, exercise play) promotes neuromuscular maturation in infants, and control of specific motor patterns (Smith 2010). *Rough-and-tumble play* (e.g., play fighting, wrestling, jokingly kicking) is a subform of physical activity play and is argued to train the social brain to develop notions of fairness, competition versus cooperation, and a sense and strategies for dealing with ambiguous situations (Pellis and Pellis 2011).

The developmental benefits of playful behavior and social interactions have been well documented and discussed (cf. e.g., Smith 2010). According to psychological and sociological evidence, the playing of games has a crucial relevance for cognitive physical and social development – although the evidence-base around this is contested (Fagen 2011).

Of the six types of play suggested by e.g., Pellegrini and Smith (2005) or Smith (2010) (some of which are listed above), namely, *social contingency play*, *sensorimotor play*, *object (manipulation) play*, *language play*, *physical activity play*, and *fantasy* or *pretend play* the categories *social contingency,* and *fantasy/pretend play* apply to the bulk of computer games. *Language play* is represented by e.g., foreign language games, *physical play* has recently seen an immense interest from the gaming community, initially due to the release of the Wii and *object play* is found in games such as Minecraft.

The First Games

Few people will be familiar with the ancient *Royal Game of Ur* which was popular in Mesopotamia 4600 years ago (Green 2008) and thereby one of the oldest games on record. A game that has survived the test of time much better is *Chess*, which is considered to have originated in fifth- or sixth-century Persia and is thus more than 1400 years old (Shenk 2007). The ancient (according to Fairbairn (2004) 4000 years old) game of *Go* surpasses *Chess* in complexity and the two are said to be the only two games to survive *"the trial of centuries without any material change in the rules"* Lasker (1960). *Go* is another game that is by some considered to be *the oldest game of all* (Smith 1956), possibly being three times as old as *Chess* Lasker (1960), with its origins dated back to Wu, a vassal of the Chinese emperor Kieh Kwei (1818–1767 BC) (cf. Lasker 1960; Smith 1956). It is said to be of great value for the exercising of the brain (Smith 1956) and became played zealously by the Samurai. It was well known in China in around 1000 BC, as poems from that time confirm (Lasker 1960). In Japan, its social importance was significant and it had influence on many aspects of daily life; by 200 BC poetry and *Go* went hand in hand in Japan (Smith 1956). The game was opposed by Confucians, not only because of its addictive nature but because of its underlying philosophical thought that *all is change and nothing is permanent* (Shotwell 2003). The game heavily relies on the formation of patterns (Park 2008) and has many analogies to warfare; indeed Shotwell (2003) mentions the famous Sun Tzu (Giles 1974) and his book *"The Art of War"* (Tzu and Cleary 1988). Another ancient game mentioned in the literature is *Nim* (Jørgensen 2009), which is said to have originated in ancient China – but dates are hard to find (Spencer 1975; Jørgensen 2009). The reader will be familiar with the game from early childhood: players take turns in removing matchsticks/pebbles/etc. from a number of piles, and the player to take the last is the loser. There are a variety of rules and versions of the game, but they all can be related back to the same class of rules and settings.

Contrary to very complex board games of *Chess* and *Go*, computer programs playing games such as *Tic-Tac-Toe* or *Nim* can be programmed easily as there are known algorithms and winning strategies for them (Bouton 1902; Conway 2001). There has been a number of machines which were programmed to play against humans e.g., *"Nimatron"* in 1940 in the USA and *"Nimrod"* in 1951 in the UK (Jørgensen 2009),

"Nimbi" in 1954 in Finland as well as in Norway (Saarikoski and Suominen 2009).

Early Computer Games

The majority of the literature on video and computer games looks at them as objects and neglects to investigate the underlying technologies (Royer 2011) and their potential (Hildmann et al. 2009; Hildmann 2009). It does not help that there is no commonly agreed upon definition for the term *game*, and certainly among technology enthusiasts there is a certain degree of uncertainty as to where the boundaries lie between work and play, or, in this case, between game and application. One could argue that finding the faulty tube in an old computer system constitutes a game, however, that would admittedly be stretching the definition. Generally, there are various opinions on what constituted the first computer game, and, more importantly, who can claim credit to have invented or written it (the literature is not entirely consistent about dates itself, our reference publications, e.g., Deane et al. (2006), Egenfeldt-Nielsen et al. (2008), Jørgensen (2009), Nyitray (2011), and Saarikoski and Suominen (2009) differ in the exact years). For those that are fond of computer games, this will not be the most important aspect; chances are each reader will have their own memory of which game they played first and where. Commonly the game *Pong* is attributed the title of being the first-born by those not in the know, however, there are records of the game of *Checkers* being developed and *Tic-Tac-Toe* being implemented as early as 1951 (Jackson 2000; Egenfeldt-Nielsen et al. 2008, respectively). The game *Nim*, mentioned above, was studied extensively and programmed in a variety of implementations available to the public (Jørgensen 2009; Saarikoski and Suominen 2009; Deane et al. 2006) after 1940, notably the New York World's Fair in 1940 (Jørgensen 2009) or the Festival of Britain in London in 1951 (Saarikoski and Suominen 2009). This notwithstanding, Nyitray (2011) dates the first computer game to be played by the general public back to 1958 (October 18, 1958, at Brookhaven National Laboratory, USA, to be precise). Nyitray (2011) also pegs that game (*Tennis for Two*, by William A. Higinbotham) to be the first game to feature interactive control as well as motion on screen, which *Nim* clearly lacked. While available to the public (and very similar in a number of ways to the version of tennis offered by the modern day Wii), *Tennis for Two* did not receive wider attention and soon disappeared of the market and never was patented.

Another game frequently remembered as being one of the very first computer games (Jørgensen 2009) is *Spacewar!*, created by Steve Russell, Alan Kotok, Martin Graetz, and others at MIT (Lowood 2009; Nyitray 2011). That game, dating back to February 1962, was originally invented to showcase the PDP-1 computer and arguably drew on the experience Russel had gained through his earlier collaboration with Marvin Minsky and his early work in games. In the fall of 1970, Nolan K. Bushnell, Ted Dabney and Larry Bryan decided to form the company "Syzygy" and to design a commercial version (i.e., coin-operated) of *Spacewar!* However, in early 1972, they found out that this name was already in use by another California company. So, in June of that year, they founded a company by the name of Atari, which, like the other names they had considered (e.g., "Sente" and "Hanne"), is a term from of *Go* indicating that a stone is about to be captured (Wolf 2009).

Computer games have become the subject of a whole field of study (Hildmann and Hildmann 2009a, b), their influence in culture has become a relevant aspect for a number of disciplines (Wagner 2006). As stated in Bogost (2007), video games are computational artifacts, and their cultural importance might just be because of that, i.e., they have cultural meaning as computational artifacts; Mäyrä (2006) dates the period when information technology and social and cultural processes became entangled as the 1970s and 1980s and claims that games like *Pac-Man* and *Donkey Kong* were so much more than *just* games

like many games before them. Computer games in that time (just like they do today) provide training and expertise in a medium (Hildmann et al. 2010; Hildmann and Hildmann 2011) that has increasingly become a central part of today's first world civilization. (Sutton-Smith 1986) observes that adaption occurs when there is something to adapt to, and conjectures that computer games are the response to the need to adapt to the computer. They might not have been invented because of this need, but they have found incredibly wide acceptance because of it. The importance of adapting to the computer is compared to adapting to the printing press in the sixteenth century (Sutton-Smith 1986).

Further Reading Recommendations

For a more detailed account of the history of computer games, the reader is referred to, e.g., Dillon (2016) or Purcaru et al. (2014). Luce and Raïffa (1989) discusses the decision-making in games. The use of games in a serious context is described in, e.g., Moseley and Whitton (2013), Hildmann (2010), or Gass (1993) and in, e.g., Ma et al. (2012) in the context of computer games. For theoretical work on game theory, the reader is referred to the standard literature in the field, e.g., Osborne and Rubenstein (1994), Davis (1997), and Binmore (2007). While there is an ever increasing amount of literature on the design and implementation of computer games, Smed and Hakonen (2017) and Günzel et al. (2010) are a good start.

Cross-References

- Computer Games and Artificial Intelligence
- Computer Games and the Evolution of Digital Rights
- Computer Games in Education
- Gamification
- Gamification and Serious Games
- Machine Learning for Computer Games

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Origin of Virtual Reality

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Synonyms

Artificial reality; Simulated environment; Simulations; Virtual reality

Definitions

Virtual reality is the experience of an artificial environment simulated by a computer. The environment is provided through sensory stimuli such as sights, sound, vibration, and even smells. Interactive hardware and software create a realistic and immersive simulation, often in a three-dimensional environment to provide a more life-like experience.

Introduction

Virtual reality (VR) technology has been around for much longer than most individuals realize. In this article, we will go through the history of VR from the beginning to the more recent accomplishments.

The History of Virtual Reality

Historically speaking, we have been attempting to create experiences that put users into virtual scenes for longer than we have had electricity. Across the late eighteenth and nineteenth centuries, the panorama was patented by the Scottish Portraitist Robert Barker in 1787, where an exhibited painting was placed on a 360-degree view, circular canvas which surrounded the

viewer (Ford 2017). They essentially entered a building that was created to house an artwork that the individuals could walk through and experience. In the 1700's, this was as virtual as it could get. Virtual reality technology could be really said to have some of its foundational roots in the 1800s, specifically with the stereoscope invented in 1839. This evolved into the View-Master, patented in 1939 and is still a popular toy today. However, this industry takes many more decades before it begins to resemble what we recognize with systems like the Oculus Rift today but still far earlier than some may realize.

In 1929, Edward Link created the "Link Trainer" on a design that he later patented in 1931 (History of Virtual Reality 2016). It was an electromechanical flight simulator that encapsulated the individual into a replica cockpit. It had motors to control a rudder, pitching, and rolling of a craft. The machine mimicked turbulence and other disturbances. During WWII, 500,000 pilots improved their skills by logging hours of initial training on 10,000 "Blue Box" Link Trainer machines. Later, the Sensorama was created in the mid-1950s by Morton Heilig, a cinematographer that patented the device later in 1962. This device had stereo speakers, a stereoscopic 3D display, fans, smell generators, and a vibrating chair. The Sensorama had six short films that were created by Morton Heilig himself.

In the 1960s and 1970s, there was a slurry of inventions that are worthy of noting. These include a continuation of Morton Heilig's work within a device called the Telesphere Mask in 1960, which was a head mounted display that significantly moved us toward what is familiar today (History Of Virtual Reality n.d.). More attention was beginning to be paid as a pair of engineers from Philco Corporation, Charles Comeau and James Bryan, as they created the Headsight in 1961. It was an incorporated system that had a screen for each eye and a motion tracking system. It was originally developed for immersive, remote viewing of dangerous situations by the military. Ultimately meant to move with the body and designed to allow the user to look around the environment more naturally; however, it lacked the traditionaal on-board computer image generation hardware and software popular today. This limited its applications in the familiar areas of video games or simulations.

The 1960s also saw the writing of the Ultimate Display concept by Ivan Sutherland; his design housed a computer-generated virtual world that was maintained in real time. The user had the ability to interact with objects in the virtual world in a realistic way and augmented 3D sound and tactile feedback. The 1965 paper laid the foundation for concepts that represent the core blueprint for VR today – such as goals of creating an experience which totally immerses the user as it evolves over time. This is happening already, as virtual reality of today will eventually unfurl into immersive reality. This will be possible in the future of Brain Computer Interface (BCI) devices and experiences in the future.

The steps it has taken to get to this rudimentary version of immersive experience is traced through a history of machines so cumbersome and heavy that a series of wires was necessary to support them during play. Without them, there could be no hope for the average user to be strong enough to even use the systems. This was true for the Sword of Damocles, created by Ivan Sutherland in 1968. It was only capable of primitive gameplay through wireframe rooms and objects. The 1960s ended with Myron Krueger, a virtual reality computer artist, who developed a series of experiences that he coined under the term "artificial reality," which was when a computer-generated environment creates responses from people and enabled individuals to communicate with each other in these environments.

"Virtual reality" received its official title in the 1980s and began to be recognized as a field of study. This occurred when Jaron Lanier, founder of the Visual Programming Lab (VPL), popularized the term virtual reality through his company when they developed a range of gear including the Dataglove and the Eyephone head mounted

display, which were major developments for a field of study called haptics. These types of systems were even used by NASA in a device called Virtual Interface Environment Workstation (VIEW), which was a head mounted display that utilized the Dataglove and other systems to provide more integration for the user (Rosson 2014).

The 1990s popularized virtual reality with the public. It was through a series of games created by Virtuality Group, whose machines enabled individuals to interact with VR goggles, video games, and immersive stereoscopic 3D visuals that even enables multiple players. Then came the Lawnmower Man movie in 1992, which the Director Brett Leonard admitted was inspired by some of the equipment coming from VPL research labs. Major players like SEGA even attempted to get into the market, with an amazing prototype that they were never able to bring to the floor – this set the stage for the true nature of the complexities of making cheaply accessible virtual reality systems.

This challenge culminated in the Nintendo Virtual Boy of 1995, it was a red and black display game system that lacked software support and a comfortable way of playing. It was discontinued a year after production and virtual reality stayed in the domains of films like the Matrix. It wasn't until the 2010s that virtual reality became a true household phenomenon, primarily with the Rift in 2012– 2014 and easily accessible cellphone to virtual reality converters found in most chain stores – if not better console systems within the electronics department.

According to Business Insider, the virtual reality/augmented reality market is projected to hover over $162 billion in 2020 (Intelligence 2016). This rapid growth is due to advances in display technology, miniaturization of electronics, and the increasing power of small devices. Within the next few decades as the technology permeates, we will see it grow in capability toward more complex technology such as immersive reality. A pursuit that has been hundreds of years in the making.

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Overview of Artificial Intelligence

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> The study of intelligence, once dominated by biologists, has for decades been a focus for computer scientists. (Kitano 2007)

Synonyms

Artificial intelligence is a wide term, often used synonymously with the terms *computational intelligence* and *machine intelligence*. It is abbreviated as *AI* and today is used by the media to refer to any remotely clever program.

Definition

Intelligence, a term which defies a unified definition, is one of the most unique human traits. *Artificial intelligence* is the reproduction of any such behavior through the programming of a machine. This section aims to illustrate the difficulty of defining the very term artificial intelligence.

Background

The term *artificial intelligence* (AI) originates from a workshop held in 1956 at Dartmouth College, New Hampshire (Brooks 2001), but its founding works predate this (Waldrop 1984b). Among these works is Alan Turing's article on "Computing Machinery and Intelligence" (Turing 1950) which opens with the question *Can machines think?*, as are, of course, the works of the ancient philosophers who pondered the questions of intelligence, rationality, and mind. The works of, e.g., Aristotle (on formal logic), Leibniz (on binary numbers and on symbolic thought), Boole (on algebra), and Babbage (on analytical engines) can all be seen as contributing factors to the field of artificial intelligence (Wang et al. 2016). Simon (1977) claimed that "[w]e are now in the early stages of a revolution in processing information that shows every sign of being as fundamental as the earlier energy revolution," but after the initial euphoria in computing science, the promised progress in the field of *artificial intelligence* has come slower than expected. In the early years, the challenges that came with the field were underestimated by experts such as Herbert Simon, who famously prophesied in 1957 that "a computer [will] be the World Chess Champion before 1967" (Hsu et al. 1995). More recent predictions (Pearson 2008), while acknowledging the failure of the field to live up to the optimistic promises of early proponents (such as Alan Turing, John McCarthy, Marvin Minsky, Allen Newell, and Herbert Simon (Brooks 2010), see below), are, however, confident that the emergence of conscious and intelligent machines is imminent. Kurzweil (2008) repeatedly predicted machine intelligence to surpass human intelligence by 2050 (Landwehr 2008). The current resurgence of artificial intelligence, which to a great extent can be attributed to advances in computing power (which in turn enabled new approaches and algorithms), led to somewhat of a hype. This hype is fueled in part by the lack of nuance when discussing the concept of artificial intelligence.

This sections draws a picture of AI that, contrary to many contemporary articles, discusses key publications and people which provided the basis of modern artificial intelligence and influenced advances in the field to this day. We attempt to give the reader an understanding of the different schools within the topic, such as the *symbolic* vs. *sub-symbolic* approach and *strong* versus *weak* AI, and introduce some of the ethical considerations since these play an increasingly important role as AI becomes a pervasive technology.

Symbolic Versus Non-symbolic AI

In their paper "Computer Science as Empirical Inquiry: Symbols and Search," Newell and Simon (1976) postulated that "[a] physical symbol system has the necessary and sufficient means for general intelligent action." Symbolic AI is based on the idea that a symbol system is a fundamental requirement for intelligence and that machines can be intelligent because they can be designed to operate a sufficiently adequate symbol system. The counterview is of course that information and concepts are not necessarily represented as symbols but instead as signals, which are processed in massive numbers and generate meaning through coexistence with other signals. Symbolic AI uses logic, rule-based, and expert systems, while non- or sub-symbolic approaches are embodied by artificial neural networks or stochastic approaches.

Early proponents of the latter were, for example, Rodney Brooks who in "Elephants don't play

chess" (Brooks 1990) claimed that "the world is its own best model. It is always exactly up to date. It always has every detail there is to be known. The trick is to sense it appropriately and often enough." Currently, non-symbolic approaches account for the majority of advances in the field of AI reported in the mainstream media. This is due to the fact that many of the recent breakthroughs are based on neural networks. In the past, however, symbolic approaches made the headlines more often though, e.g., Mycin (Shortliffe 2012), an expert system for the diagnosis of infectious diseases, or ELIZA (Weizenbaum 1966), the first "chat bot" which was a simulation of a psychotherapist.

Strong Versus Weak AI

Another view on the world of artificial intelligence is through the dichotomy of strong versus weak AI. Weak AI makes no claims to truly implement intelligence and instead only talks about machines that implement very specific functions. Strong AI in contrast talks about *true* intelligence and about machines actually having a mind, just like humans. All current systems are weak AI systems as they are not making use of a general approach but are always purpose-built. A similar and somewhat less contentious view is to divide the field into engineers, who "are trying to get their programs to do smart things, by whatever means they can," and scientists, who "are after a general theory of intelligence, both human and machine" (Waldrop 1984b).

The question really is whether mankind is ready to accept the notion of machine intelligence. As Weizenbaum (1972b) illustrates, scientific insights gained have, throughout time, often result in humiliation. Understandably so, for as one learns the reason behind certain phenomena, one will have to revise the explanations previously adapted for them. The examples given are the classic ones, which have then (and in some cases still do today) been ridiculed and fanatically argued against: Galileo for challenging the notion of earth being the center of the universe; Darwin for providing an alternative – and rational as much as plausible – answer to why things in nature seem so well *designed*; and Freud for shattering the illusion of rationality. The more mathematically inclined reader might want to add Kurt Gödel, for proving Peano arithmetic (Shankar 1994) to be incomplete and thereby single-handedly throwing mathematics into a crisis of faith (cf. Wang 1997; Hawking 2007).

Intelligence is often considered a unique thing, something that, for religious or philosophical reasons, sets humans aside from anything else in the universe. Creating it artificially is to many an attack on the very foundations of their view on the *self* and the universe. Instead of raising machines to the level of intelligence, we are much more likely to reduce the notion of our own intelligence to, e.g., some emergent property of the complex system that is our brain. Independent of the fact that philosophy has long since chipped away at core concepts such as the idea of having a *free will* (Smith 2011), the *rationality* of our actions, the emotion *love*, and, ultimately, the notion of *consciousness*, accepting the artificial creation of intelligence in machines would cause a major crisis of faith to many. In the end, the jury is still out on whether artificial intelligence will ever be "truly" intelligent or if machines can have a mind. However, independent of what the answer will turn out to be, AI is very real, and its ethical implications need to be discussed.

Ethical Considerations

As the use of AI in everyday life becomes more ubiquitous, questions about ethical considerations need to be asked. These questions range from implications on the workforce (e.g., the loss of many blue-collar jobs) over responsibilities of actions of AI systems (e.g., accidents by self-driving cars) and bias due to skewed training sets (e.g., cheaper mortgages for Caucasians) to the question whether certain systems that *can* be built *should* also necessarily be built (such as autonomously operating weaponized drones). Most current AI systems are *decision-support* systems, rather than *decision-making* systems. This implies that the ultimate responsibility for

the actions taken lies with the human. We are now at a stage where such intelligent systems perform near or above human level. However, for decision support systems, the ultimate responsibility lies with the human, but the responsibilities for the actions of such systems have yet to be decided.

Obvious examples of this conundrum are about the use of autonomous vehicles, where decisions about life and death of passenger and passersby might have to be taken. These discussions appear more regularly now, with heads of the largest high-tech firms publicly arguing for or against the threat that AI, especially when combined with networked machines and robots, can that AI can pose, especially [. . .] machines and robots. These discussions have been ongoing for a while.

For example, Weizenbaum (1972b) and Wiener (1960) wrote on the moral and ethical issues of AI and allowing computers to make decisions; the latter being criticized by Samuel (1960) and the former by Coles (1972). In the end Weizenbaum rebuts (Weizenbaum 1972a) the argument by emphasizing again the dilemma of this period, i.e., the question on the responsibility of the researcher to consider what his research does and the issue of the *common man* meddling, through elected politics, with things outside his intellectual regime of competence. As far as the individual's responsibility is concerned, however, the common *man* (or, as in this case, woman) seems to agree with him (Holmes 1973). The above recounted string of statements and attacks thereon, followed by rebuttals and counter-attacks, while quite amusing to read, instills the image of the research community in the 1970s and 1980s being childlike and simple (which, given the topics discussed, seems ironic).

Application Areas

As Waltz and Buchanan (2009) point out, from their earliest days computers were used to automate calculations according to predefined instructions. Buchanan et al. (1968), working with Edward A Feigenbaum, created DENDRAL, which was among the first systems that would attempt to go beyond this and effectively *interpret* data, instead of simply performing calculations on it. Leveraging the potential of greatly sped up calculations in combination with large collections of expert knowledge (collected painstakingly from human experts), such *expert systems* became one of the dominant areas of AI at the time. With increasing data generation capability naturally comes the need for systems that can process these growing amounts of data. King et al. (2004) argue that without automation we simply lack the ability to analyze all the data we generate and suggest going further: King et al. (2009) report on an entirely automated biology lab where machines perform the experiment design and implementation, collect and interpret the data, and use the latter to inform the former. Schmidt and Lipson (2009) discuss automating the process of conjecturing and verifying analytical natural laws in the field of mathematics and physics. However, the advent of this brave new world where machines conceive entirely new ideas fit to spark a scientific revolution is not undisputed. Anderson and Abrahams (2009), for example, remind us that according to Kuhn (1962) there is more to science than the generation of new knowledge *within* the boundaries of existing beliefs and that the rare, but occasional *paradigm shifts* that occur within a field are the milestones along which advances in sciences are measured. Whether machines can match humans in their ability to *think outside the box* remains to be seen.

Today, applications of artificial intelligence techniques can be found in a large number of fields (Hildmann and Crowe 2011). Examples cover virtually all areas of scientific investigation, ranging from the autonomous discovery of laws in natural sciences such as physics (Schmidt and Lipson 2009) over the interpretation of mass spectra in cell biology and chemistry (Yates 2011) to mapping the synaptic connections of neurons to neuronal functions in neuroscience (Seung 2011). AI is also used in applied psychology and game-based learning where serious games are driven by AI players specifically designed to create game experiences tailored for individual human players (Hildmann and Hildmann 2012a, b). In addition, commercial applications for AI are equally pervasive with, e.g., the movie

industry using AI techniques to create and simulate entire physical environments and simulate lighting conditions and lighting effects in animated movies (Lewinski 2011).

Landmark Publications

With a field which spans multiple research areas and is as diverse as artificial intelligence is, today it is difficult to compile a list of landmark publications that does justice to all the advances and seminal contributions. While this is not a complete list by any means, the following papers certainly deserve to be included: "On Computable Numbers, with an Application to the Entscheidungsproblem" (Turing 1936 – proof of the decision problem that there is no algorithm to always decide whether a formal statement is true in a system), "Computing Machinery and Intelligence" (Turing 1950 – introduction of the Turing test), "A Behavioral Model of Rational Choice" (Simon 1955 – rational behavior must be compatible with information access and computational capacity), "Computer Simulation of Human Thinking" (Newell and Simon 1961 – argues that human behavior can be explained using natural sciences and laws alone), "GPS: A Program that Simulates Human Thought" (Newell and Simon 1963 – introduces the General Problem Solver, a computer program that replicates human thinking), "Some Philosophical Problems from the Standpoint of Artificial Intelligence" (Mccarthy and Hayes 1969 – introduces the frame problem, how to describe the world using logic without adding large numbers of (obvious) statements), "Computer Science as Empirical Inquiry: Symbols and Search" (Newell and Simon 1976 – poses the physical systems hypothesis that states that physical symbol systems have necessary and sufficient means for intelligent behavior), "What Computers Mean for Man and Society" (Simon 1977 – discusses predictions around computers and artificial intelligence), and "Machines Who Think" (McCorduck 1979 – one of the first detailed discussions on the history of AI, based on interviews with key figures).

Key Figures

Today the field of artificial intelligence transcends almost all walks of life. It is found in anything from public transport to research into theoretical mathematics and the finance markets. Compiling a comprehensive list of key figures is impossible; at best an entire book might suffice to list key figures in all the subfields now belonging to AI. The select few listed below are meant to be representatives, in part chosen because their works are referenced substantially in this encyclopedia. They are people that have led and inspired; their names represent entire fields, research groups, and institutions.

Allan Turing (*1912–†1954)

Allan Turing's contribution to artificial intelligence and the field of computing science is repeatedly mentioned below. He is famously known for both the *Turing machine* (Turing 1936) and the *Turing test* (Turing 1950); his importance to the field is also reflected in the fact that the *ACM A.M. Turing Award* (http://awards.acm.org) – computer science's highest honor (Campbell-Kelly 2007) – bears his name. As early as 1947, Alan Turing described the human brain as a "digital computing machine" (Turing 1995). He also postulated that the assumption of infallibility (in the context of machines) excluded the ability to exhibit intelligent behavior, though the reverse phrasing is probably closer to what he meant, namely, that intelligent machines cannot be infallible.

Among Turing's best known achievements is the proof that there are formal limits to computation, which he famously did by showing that the *halting problem* is undecidable (Turing 1936). Already in the 1940s, Turing maintained that "a computer could play 'very good chess' if 'occasional serious mistakes' were allowed"; his argument being that by allowing for mistakes "Gödel's incompleteness theorem becomes irrelevant" (Hodges 2007).

Alan Turing devised a theoretical machine (known as the *Turing machine*) that could read and write from an infinite tape, move along this tape to any position on it, and execute a finite

set of instructions. He then showed that such a machine could be fed the description of such a machine and execute it faithfully. This machine is, in essence, the idea of a programmable machine and as such describes today's computer hardware. The instructions fed to such a machine are, in turn, describing today's computer software. Therefore, by describing his so-called Universal Touring Machine, Alan Turing described the computer of today (Strawn 2014). Furthermore, *Turing completeness* and the *Church-Turing computability* are also landmark contributions to theoretical computer science. In addition to being maybe the most famous representative of the field of AI, Turing published landmark papers in biology and played an integral role in breaking codes during World War II.

Tragically and despite having played an integral role in saving Great Britain in World War II from fascist Germany, the UK government turned on him for having relations with another man. Given the choice between the public humiliation of a prison sentence and chemical castration, he chose the latter. Subsequently, as a direct result of this treatment, Turing took his own life on June 7, 1954, at the age of 41 (Strawn 2014). It has taken the UK government 65 years to even apologize for this injustice (in September 2009, British Prime Minister Gordon Brown made an official public apology on behalf of the British government for *the appalling way [Turing] was treated.* On Christmas Eve 2013, Queen Elizabeth pardoned Turing posthumously (Strawn 2014)), and still today, many articles written on the occasion of his 100th birthday (e.g., Severance 2012; Lipton 2012) fail to even mention the reasons that led to his death.

Marvin Minsky (*1927–†2016)

Marvin Minsky, winner of the 1969 ACM A.M. Turing Award, is generally considered one of the pioneers of artificial intelligence and robotics (Hassler 2016). He believed that machines can be intelligent, that they can match human performances, and that this would happen in his lifetime.

Together with John McCarthy, Marvin Minsky founded MIT's AI lab in 1957 (Hassler 2016). Together with Seymour Papert, he conceived the *Society of Mind* and developed this speculative cognitive science and philosophy theory (Strawn and Strawn 2016) from the early 1970s onward. He later published a seminal book by the same title (Minsky 1988). He basically postulated that the human mind is comprised of a collective of agents for various different tasks and challenges and that it is in fact the collective (the *society* of these agents) that makes up our mind (Strawn and Strawn 2016).

In 1972, together with Seymour Papert, he published the highly controversial book *Perceptrons: An Introduction to Computational Geometry* (Minsky and Papert 1972). In it the authors show that certain neural networks are limited in computational power and that there are certain things they cannot learn. Whether intentionally or due to being misunderstood by the field is still a debate today, but as a result of this book, funding and support for neural networks (i.e., for non-symbolic AI) dried up for roughly a decade (Olazaran 1996; Strawn and Strawn 2016). This created a mind-set that diverted efforts and support from the field and which might have persisted until the rather recent success and victory march of Deep Learning, which might very well have played a crucial part in changing how artificial intelligence is perceived by the public. For quite a while there was the widespread notion of a *winter of AI*, representing the sentiment that the promises made had all failed, but the return of neural networks to advance the field of AI and leap-frog to what is considered by many *ahead of its time* certainly demonstrates the outstanding performance potential of artificial neural networks.

John McCarthy (*1927–†2011)

John McCarthy, winner of the 1971 ACM A.M. Turing Award, is arguably the "father" of artificial intelligence as it was him who coined the term *artificial intelligence* in 1955 when proposing the workshop held in 1956 at Dartmouth College, New Hampshire (Brooks 2001). Together with Marvin Minsky he founded MIT's AI lab in 1957 and 5 years later, in 1963, Stanford's AI lab. One of his great achievements

was the development of the logic-based programming language LISP which was proposed by him in 1957 (McCarthy 1960). This puts him in the camp of symbolic AI, and he was an important influence in the use of logic in artificial intelligence.

He was also thought to have developed the so-called alpha-beta pruning algorithm (Knuth and Moore 1975) that allowed computer to more efficiently play games such as chess. However, his influence was arguably greater in the philosophical discussions around intelligence and whether machines can be truly intelligent (McCarthy 1959; Mccarthy and Hayes 1969). He believed that "It's difficult to be rigorous about whether a machine really 'knows', 'thinks', etc., because we're hard put to define these things. We understand human mental processes only slightly better than a fish understands swimming" (Mccarthy 1983).

Herbert Simon (*1916–†2001)

Herbert Simon, winner of the 1975 ACM A.M. Turing Award as well as the *Nobel Memorial Prize in Economic Sciences* in 1978, has been called by some a *father of artificial intelligence* (http://www.post-gazette.com/obituaries/20010210simon2.asp). Simon (1955) explored and defined the concept of rational choice for *organisms, including man*. The definitions and the model he provides are, however, quite discrete and he makes repeatedly reference to computers. In a publication titled "Computer Simulation of Human Thinking," Newell and Simon (1961) argue that we can reduce the observed human behavior to chemical and physical mechanisms.

Simon (1977) claims that any limits to computer intelligence are also limits to human intelligence and thus that there is – in theory – nothing that stands between machines achieving human-like intelligence. He points out that the question whether it *can* be done might not be what is holding us back. Instead he identifies the fundamental question to be a threating one (to many people) and one of a more philosophical nature altogether: what does it mean, if it can be done? As Darwin's and Copernicus' ideas before, the concept of *artificial* intelligence challenges the uniqueness of humans, in this case, the uniqueness of *human* intelligence, that is, it questions our position in the model of reality we entertain. After all, if machines can be intelligent (and if we are only the product of long series of modifications aiming to adapt to changes in our environment, which also happens *not* to be the center of the universe), what then makes us any more significant than the rest of the matter in the universe? How can we justify our sense of self?

In Simon (1977) he states the belief that *it is entirely possible for programs to modify themselves - that is, to learn*. Consequently, his follow-up questions focus on the extent to which human behavior can be simulated by a computer and which of our activities computers should be allowed to replace. He predicted that we *are now in the early stages of a revolution in processing information that shows every sign of being as fundamental as the earlier energy revolution. Perhaps we should call it the Third Information Revolution. (The first produced written language, and the second the printed book.)*. Simon even considered using computer simulations to explore the human mind by psychological research (Simon 1977).

Edward A Feigenbaum (*1963–)

Edward A Feigenbaum is the winner of the 1994 ACM A.M. Turing Award (jointly with that of Raj Reddy), for "pioneering the design and construction of largescale artificial intelligence systems, demonstrating the practical importance and potential commercial impact of artificial intelligence technology." In his dissertation, completed in 1959 under the supervision of Herbert Simon, he developed one of the earliest computer models for human learning.

In the late 1960s (Waldrop 1984a), he developed Heuristic DENDRAL (Buchanan et al. 1968; Yates III 2011; Waltz and Buchanan 2009), a program used to investigate chemical structures at a professional level and is considered as one of the (if not *the*) *father of expert systems*. His work on knowledge engineering and expert systems has affected almost everybody, be it in the form of Microsoft's dreaded paper-clip wizard

assistant or any other knowledge database interface. His work led to a boom in expert systems and caused increased interest – and investment – in the field of AI.

One of his key areas of interest was heuristics, i.e., means to approach and find good solutions to computationally hard problems (as opposed to deterministically deriving the best possible solution). In today's increasingly connected and complex world, heuristics may be a load-bearing pillar that drives enterprises in areas ranging from resource allocation over scheduling to Big Data and the Internet of Things. Though less known, his legacy is everywhere.

Norbert Wiener (*1894–†1964)

Norbert Wiener was an early protagonist of stochastic processes, nominated (alongside Shannon) for the 1959 Nobel Prize in Physics. He was full professor of mathematics at MIT, and the *Norbert Wiener Prize in Applied Mathematics* is named after him. Norbert Wiener is considered to be the founder of *modern* cybernetics (Bardis 1965) and worked on important contributions and theories in the fields of robotics and automation.

He is considered as a key figure in the field of AI here for a number of reasons, among which is the fact that he was involved in the building of the cognitive science team at MIT which would go on to make landmark contributions to the fields of computer science and artificial intelligence. He collaborated with von Neumann on models for neurons and like Shannon worked on early investigations into information theory.

Wiener (1960) challenged an opinion he felt was common with *the man in the street* (and, as pointed out by Samuel (1960), also by some men of science): the assumption that machines cannot possess or exhibit originality. He did in fact believe that the opposite was possible, i.e., that machines can possess originality (Samuel (1960)). He was not alone in his views, as contemporaries such as Johnson and Kobler (1962) shared his beliefs. In this paper he elaborates on game-playing machines, specifically mentioning *chess*.

Final Thoughts

It is clear that a complex and controversial topic like artificial intelligence that touches onto almost any domain and influences many of today's technological accomplishments cannot be adequately described in a few pages. Instead of aiming for an incomplete overview, we have tried to provide the reader with a sense of history and the references to go on an expedition into the origins of artificial intelligence, the mind, and ultimately the question of what it means to be human.

Cross-References

- ▶ Challenge-Based Learning in a Serious Global Game
- ▶ Computer Games and Artificial Intelligence
- ▶ Computer Games and the Evolution of Digital Rights
- ▶ Computer Go
- ▶ Gamification
- ▶ Gamification and Serious Games
- ▶ Machine Learning for Computer Games
- ▶ Monte-Carlo Tree Search
- ▶ Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

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Overview of Virtual Ambisonic Systems

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Synonyms

Ambisonic binaural rendering

Definition

A surround sound method that combines binaural audio reproduction methods with ambisonic surround sound technology.

Introduction

Virtual ambisonics is a method that combines binaural audio simulation and the surround sound reproduction method known as ambisonics. This entry gives an overview of the basic psychoacoustic theories behind binaural hearing, methods to simulate binaural hearing, and the issues that may arise from these simulation methods. This is followed by a brief description of ambisonics and how it can be combined with binaural audio to create virtual ambisonics.

Binaural Hearing

Binaural hearing describes how humans are able to locate a sound source in three dimensions using two ears. A listener can identify sound sources based on the difference between the time of arrival (interaural time differences or IDT) (Wightman and Kistler 1992) or the difference in intensity levels (interaural level difference or ILD) (Hartmann and Constan 2002). Listeners also identify the location of sound sources due to filtering effect caused by the shape of the pinnae (Hofman et al. 1998). Listeners use head movements in order remove ambiguity in regard to the location of the sound source (Perrett and Noble 1997). Non-biological cues are also involved, with perceived source distance being associated with how reverberant the sound source is (the precedence effect) (Litovsky et al. 1999).

Head-Related Impulse Responses and Head-Related Transfer Functions

Due to complexity and nonlinearity of human hearing, it is necessary to use head-related impulse response (HRIR) to capture the

characteristics of human hearing. A simple HRIR can be captured using a binaural dummy head with omnidirectional microphones placed in each ear of the dummy. The dummy head is placed inside an anechoic chamber, and an impulse response or sine wave sweep is played through a loudspeaker and recorded via the dummy head. This can be used to generate head-related transfer functions (Jot et al. 1998; Hammershoi 1996; Hammershoi and Moller 2005). A head-related transfer function (HRTF) is what is obtained after carrying out a Fourier transform of a HRIR. The HRTF describes the filtering of a sound source before it reaches the eardrum.

In order to synthesize a virtual sound source, a HRIR for the left and right ear is convolved with a sound source that was recorded using an omnidirectional microphone in an anechoic chamber (Jot et al. 1998). This convolved output is then sent to their respective left and right headphone outputs. The HRIR used is dependent on the direction that the sound source is coming from. It is important to note that this method only works using headphones and that these binaural simulation techniques do not work using stereo loudspeakers.

A major issue surrounding binaural simulation using HRIRs is that each sound source requires its own HRIR. For a large number of HRIRs, the computational cost of so many convolution operations can be great. Furthermore, moving sound sources require complicated interpolation between the different HRIRs. This is further complicated by the fact that humans implement head movements in order to fully determine the location of a sound source that falls within the cone of confusion. For this reason, the use of HRIRs to simulate binaural hearing is usually inappropriate for real-time situations. This is particularly true in the case of VR, where a sound source's location may be controlled using AI.

Ambisonic Systems

Ambisonic systems utilize a (usually) spherical array of loudspeakers that allow the user to position a sound source through a series of encoding and decoding algorithms that recreate the sound field. The audio file format used by ambisonics is called the B-format. It consists of two types: first-order B-format and the more recent higher-order B-format (Furness 2011).

First-order B-format contains four audio channels, designated the W, X, Y, and Z channels. B-format is designed to recreate the sound field using spherical harmonics. The mathematics that describes ambisonic systems is beyond the scope of this entry. For an overview, the reader is pointed to Fellgett (1973). Higher-order B-format adds more audio channels to the format, corresponding with higher-order spherical harmonics (Nettingsmeier and Dohrmann 2011).

Sounds may be captured for use in first-order B-format using a sound field microphone. This specialist microphone is actually four microphones combined: an omnidirectional microphone and three figure-of-eight microphones. The positioning of the figure-of-eight microphones corresponds to the X, Y, and Z axis and captures information on how the sound source is affecting the air pressure at the point of recording. The omnidirectional microphone is used as what is called the reference channel. These four audio channels are used to recreate the sound field in an ambisonic system.

Ambisonic panning is a two-stage process known as encoding and decoding. The encoding process is where a user may pan mono sounds. This is done by specifying the sound source position by specifying the location in terms of angles for the horizontal and vertical plane. The decoding process involves adjusting the decoding parameters to the speaker array currently in the room. This design choice means that the encoding of audio mixes remains unchanged, but can adapt to the speaker layout of the user.

Virtual Ambisonic Systems

Virtual ambisonic systems combine the two methods described in the previous section and were first described in Noisternig et al. (2003). It works by routing the output of the decoded ambisonic signals to HRIRs corresponding with the location of the speaker. This in effect creates

a virtual speaker. The outputs of these HRIRs are sent to the respective channels of the left and right headphone output, recreating the ambisonic system.

There are a number of advantages to this type of system. Firstly, virtual ambisonics limits the number of convolution operations to twice the number of virtual speakers being used in the decoding process. This means that it is particularly useful for a large number of sound sources. It is also useful for moving sound sources, as it avoids the need for any type of complex interpolation between HRIRs as the sound source moves location. This panning effect is also useful for implementing head motion tracking and shifting the location of the sound sources to correspond with the listener's head position via motion tracking.

Implementations

Ambisonics has recently become available for use in Unity VR through a plug-in from Google. For a tutorial on this topic, please see Ambisonic Audio (2017). Most implementations of virtual ambisonics have been restricted to academics researching the topic (Gorzel et al. 2011; Braun and Frank 2011; Kearney et al. 2012). However, in theory, it should be possible to implement it by routing the output of the ambisonic system to be convolved with the corresponding HRTFs. A library of HRTFs is available at Wierstorf et al. (2011) and Bernschütz (2013).

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Overwatch: Team-Based Multiplayer First-Person Shooter Game

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Synonyms

First-person shooter (FPS) game; Multiplayer game

Definitions

Multiplayer game = a game that is designed for multiplayer mode where two or more players are expected throughout the entire gameplay.

First-person shooter (FPS) game = a video game where a player takes on a first-person perspective when using gun and other weapons in combats.

Introduction

Overwatch is a 2016 team-based multiplayer first-person shooter (FPS) game developed and published by Blizzard Entertainment for PC, Xbox, PlayStation, and Nintendo Switch. Overwatch is set in a future where a conflict between robots and humanity necessitated the creation of a task force, conveniently called "Overwatch." In the game's primary competitive mode, players are arranged into two teams of six and compete on a variety of maps and game types. This allows the gamers to play in whatever way they believe is the best such as flanking or working together to push to the point on the map or allow for people to get in the backlines and take people off on both sides.

6v6 Team-Based Gameplay

Overwatch assigns players into two teams of six, with each player selecting from a large roster of characters, known as "heroes" with unique abilities (See Fig. 1). The teams use a variety of weapons such as guns, hammers, and turrets to secure point or move payloads to checkpoints. With Overwatch's 21 different maps to play on, it is always exciting to see where you end up fighting. Maps are split into four different play modes: assault, escort, hybrid, and control. Assault or "2CP" has a team trying to capture two objectives on a map within a set time. Escort is a mode in which teams are on either offense or defense. The offense team attempts to move the payload to objective points on a track within a timeframe whereas the team on defense attempts to stop the progress until time runs out. Hybrid is a combination of the two previous modes where the defense team attempts to stop the offense team from taking the objective and moving the payload further into the map. Control is a mode in which teams attempt to fight over a specific area of a map. This can be from the inside of a temple to the common area of a small town. Teams are equally spread out so that each can get to the point at the same time. There is also a variety of other game modes which range from low gravity – allowing characters to float in the air for a while, all the way to no limits – allowing all players to play the same characters if they wish, which is not the case in unranked or ranked modes. Ranked is a game mode where many people play to rise in the ranks ranging from bronze to grandmaster.

A Brief Beginner's Guide

With a steep learning curve, Overwatch is a game that is difficult to master. However, it is easy to get started in playing Overwatch:

Overwatch: Team-Based Multiplayer First-Person Shooter Game, Fig. 1 Hero gallery

1. Purchase hardware: Overwatch runs on a variety of platforms including PC, PlayStation, Xbox, and Nintendo Switch.
2. Install Overwatch: Overwatch 2 is free to download and play.
3. Create an account: After installation, a player will need to create an account on the Overwatch website. However, players who already have a Battle.net account can sign into Overwatch.
4. Choose your hero: In Overwatch, the player chooses a hero with unique abilities and strengths. The player can switch between heroes during the game to adapt to the dynamic situation.
5. Play a game: The player can choose from several game modes, including Quick Play, Competitive, and Arcade. Quick Play mode offers a casual setting for players to get familiar with the game. Competitive mode provides a ranking system in a more serious setting for players to compete against other players. Arcade mode are frequently changing game modes and rules.
6. Communicate with team members: Overwatch is a team-based game, and therefore communication is key. Players use voice chat or text chat to communicate and coordinate attacks.
7. Work together: Teamwork is essential in Overwatch. All team members must work together to capture objectives, defend key positions, and defeat the opponent team.
8. Practice makes perfect: Overwatch has a steep learning curve, and therefore it takes a lot of practice to become proficient at the game.

Reception

In the first week of release over seven million copies were sold worldwide, becoming one of the top selling games in May 2016. As more characters and maps were added to the game, more players joined and the game grew steadily over time. Special events such as Halloween brought Junkenstein's Revenge which is a mode where an endless wave of robots would swarm at a castles door that the players have to protect with a limited number of characters available and can be augmented with modes that can periodically change what character you are. Another event that many people look forward to each year is Christmas which offers more modes that are not normally available, with new skins and emotes that can only be obtained in the Christmas event. However, Blizzard has become complacent with the game, believing it had become perfectly balanced and did not need to be changed, leaving

players to make the game fun themselves. With the release of Overwatch 2 in October 2022, the sequel becomes a free-to-play game.

Esports

Overwatch has its own league of 20 teams that have played about 40 matches, each lasting anywhere from 45 min to 2 h long. (Almughrabi et al. 2022) Six teams with the best records of the year go on to the playoffs ending in the top teams splitting a winning prize pool of $1.5 million dollars. There is also the Challenger Cup which is one step below the overwatch league that competes for a few days to show off their skills for the possibilities of being signed by the leagues.

Conclusion

Overwatch has sold over 50 million copies (Radić 2021). With the launch of Overwatch 2, players have lost the ability to play the original version of the game (Holt 2022). Gamers are forced to play Overwatch 2 if they wish to play the game. But this can breathe new life into Overwatch by allowing more players to join due to the free-to-play business model. It was a rough start when Overwatch 2 was released to the public with long queue times and players being disconnected for seemingly no reason (Lowry 2022). With bug fixes and the promise of a constant release of cosmetics maps and new characters, Overwatch 2 remains one of best competitive team-based multiplayer first-person shooter game.

Cross-References

▶ First-Person Shooter Games, A Brief History

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P

Pacing

► Meta Artificial Intelligence and Artificial Intelligence Director

Panda3D

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Synonyms

3D rendering; Engine architecture; Game engine; Scene graph engine

Definition

A game engine (Gregory 2018) is a software engine/framework mainly designed to develop video games while providing built-in libraries, tools, and/or components for game development-related functionalities such as model rendering, physics, levels, animations, networks, audio, and artificial intelligence (AI).

Three-dimensional (3D) rendering is the concluding stage of creating two-dimensional (2D) images from 3D models, followed by creating 3D models and adding material and light to the objects and the environment in a scene (Saito and Takahashi 1990).

A scene graph is a data structure representing the spatial and logical connections of the elements in a graphical scene via a collection of nodes (Fisher et al. 2011). It is commonly used in game engines and computer graphics libraries and software.

Introduction

Panda3D (Goslin and Mine 2004) is a free and open-source game engine under the revised Berkeley Software Distribution (BSD) license as of May 28, 2008, to develop video games, simulations, and visualizations using programming languages of Python and C++, initially developed by Walt Disney Company's Disney VR Studio and currently maintained by Carnegie Mellon University's Entertainment Technology Center. The default game development language of Panda3D is Python, and the C++ programming language is the alternative language, while the Panda3D engine is written in C++.

Panda3D aims for the users to grasp the main functionalities in a short time and targets users with diverse experiences, from novice to senior game developers, industry professionals, designers, and academic communities by providing different sets of resources and documentation such as Panda3D manuals and application

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programming interface (API) references available for both Python and C++ programming languages, focusing on game programming, debugging, and performance optimization – with additional resources such as video lectures and glossary.

Panda3D has an active community contributing to the development of Panda3D code on the project's GitHub repository, responding to questions from the users on the forum, and also supporting the project financially.

Main Features of Panda3D and Example Games

Panda3D was written in the C++ programming language and is cross-platform compatible. Panda3D source assets can be updated and modified using its command-line tools, allowing the content pipeline to be automated and scripted so that the users can create customized content in a short amount of time. Panda3D features bindings for a variety of third-party libraries, including the Bullet physics engine, the Assimp model loader, and sound libraries like OpenAL (cross-platform 3D audio) and FMOD (sound effects), allowing for the integration of external resources with a focus on the code's reusability. Panda3D users can create their own rendering and graphics pipelines, allowing them to create complex end-to-end production pipelines. Performance profiling is accomplished with the pstats profiling system, allowing the performance of the generated output to be examined so that additional optimizations can be further implemented. Finally, Panda3D enables quick prototyping and provides an easy-to-use and end-to-end pipeline for creating an initial prototype while giving an easy-to-learn foundation to the users (Panda3D 2023).

Panda3D has enabled the development of various commercial games. Toontown Online (Mine et al. 2003) was a massively multiplayer online role-playing game released in 2003 and shut down in 2013 and allowed users to create their game characters and engage in combat and non-combat activities. Pirates of the Caribbean Online (Pirates Online 2023) game was released in 2007 and discontinued in 2013, a multiplayer game based on the Pirates of the Caribbean franchise. A Vampyre Story (A Vampyre Story 2023) was another mainstream video game built using Panda3D and launched in 2008, where the game's story revolved around a vampire opera singer in Europe during the 1890s. Ghost Pirates of Vooju Island (Ghost Pirates of Vooju Island on Steam 2023), a visual adventure game, was another single-player commercial video game created utilizing Panda3D.

Conclusion and Discussion

Open-source and free-to-use game engines have revolutionized both the gaming industry and academia in terms of democratization of content generation while acting as catalysts and bridges toward diminishing the gaps within these two communities. Accessibility, availability, automation, and AI-based aspects of these advanced pieces of software and frameworks have benefited small game companies and academic research groups within universities in particular. Access to the resources, forums, and communities created around these engines has provided equal opportunities to hobbyists and commercial game firms, as well as a noteworthy boost to the rise in interest in game development and content creation. Higher education game development programs, theme-based game jams, advancements in hardware performance, and the emergence of virtual reality, augmented reality, and mixed reality headsets have massively transformed the game development domain. Furthermore, having long served as a testbed for AI tools, advancements in the game development software and hardware have made a huge impact on game AI, procedural content generation, and reinforcement learning – with recent human-level achievements in the game AI. Finally, current large language model-driven chatbots and tools have aided and enabled the creation of complex and sophisticated game content.

The road paved by the accessibility of game engines, where reaching resources, information, and hardware has enabled a fresh perspective full

of new possibilities, is predicted to lead to new and exciting journeys as well as advancements, creativity, and accessibility in game development.

Cross-References

- ▶ High-Performance Many-Light Rendering
- ▶ Virtual Reality Game Engines
- ▶ Virtual Reality Systems, Tools, and Frameworks

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Pandemic

▶ Protection Korona: A Game Design on Covid-19

Paper Prototyping

▶ Analog Prototyping for Digital Game Design

Paracommunication

▶ Parasocial Phenomena in Video Games

Parameterization

▶ UV Map Generation on Triangular Mesh

Paranodal Play

▶ Video Game Culture in Cape Town, South Africa

Parasocial Interaction

▶ Parasocial Phenomena in Video Games

Parasocial Phenomena in Video Games

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Synonyms

Paracommunication; Parasocial interaction; Parasocial relationships; PSI; PSP; PSR

Definition

The term parasocial is used to refer to interactions by consumers with a media persona via

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technology. The term was originally used as a descriptor of one-sided interactions with television or radio personalities designed to create intimacy. However, further research on these phenomena have begun to broaden the definition in response to the digital age. Researchers have begun to investigate the term's applicability to interactions which include simulated reciprocity, such as in video games by nonplayer characters (NPCs), and social interaction mediated via technology that blurs the line between parasocial and social interaction. Furthermore, the term "parasocial" is no longer confined in its use to the creation of intimacy, and theories of parasociality are beginning to be applied to other kinds of mediated relationships, which are as varied as social interaction.

The Origin of the Theory of Parasocial Interaction

What we today refer to as parasocial phenomena began as the theory of parasocial interaction (PSI). The term "parasocial interaction" was coined by sociologists Horton and Richard Wohl (1956) in their paper subtitled "Observations on Intimacy at a Distance." Horton and Richard Wohl (1956) defined parasocial interaction as one-sided social engagement mediated via a mass media figure (such as a television personality) that elicits a feeling of intimacy from the viewer akin to the experience of a "face-to-face relationship between spectator and performer." This engagement is different from exchanges with friends or acquaintances as it can only be "one-sided" (Horton and Richard Wohl 1956). Though one-sided, parasocial interaction is similar to more traditional social interaction in how it is formed and maintained; the interviewer may judge the on-screen actor by first impression and "through direct observation and interpretation of [their] appearance," which breeds familiarity with the figure over time, leading to the building of a "history" through "accumulation of shared past experiences" (Horton and Richard Wohl 1956). This first study identified techniques used in personality programs, such as talk shows, designed to make viewers feel a sense of intimacy with their hosts. Such techniques include having hosts mimic the "conversational style, and milieu of an informal face-to-face gathering," which gives "the impression that he is responding to and sustaining the contributions of an invisible interlocutor" (Horton and Richard Wohl 1956). Hosts may also play a part in intentionally blurring the line between observer and performer by sitting with a studio audience or taking calls from viewers at home (Horton and Richard Wohl 1956). Rosengren and Windahl (1972), drawing inspiration from Horton and Wohl, created a "typology of relations" split into four kinds of relationship with two overlapping categories, "interaction" and "identification" (p 173), which was further modified in 1976 by Rosengren, Windahl, Hakansson, and Johnsson-Smaragdi. The most commonly used scale was developed by Rubin, Perse, and Powell (1985) whose 10-item version is the most widely applied. Further development on such scales continues, as detailed in Auter and Palmgreen's (2000) work, in which a summary of prior scales can be found.

Parasocial Phenomena

The lack of consensus surrounding the definition and measurement of PSI has resulted in conceptual confusion regarding its definition. This has led to a plethora of attempts to clarify the concepts and consider how they may be used more consistently. Liebers and Schramm (2019) coined the term "parasocial phenomena" (PSP), which is useful shorthand for describing a broad spectrum of PSI as it encompasses all types of parasocial activity including "parasocial interactions, parasocial relationships, parasocial breakups, and so on." The most important distinction they draw is between parasocial interaction and parasocial relationships (PSRs). Liebers and Schramm (2019) use the term parasocial interaction to define interactions with a media figure that occur during media consumption, and parasocial relationships to describe parasocial phenomena that move beyond the confines of media consumption and "encompasses cross situational relationships

between the audience and media characters." Considering this definition, one may see parasocial interactions as fleeting encounters which, over time, make up the parasocial relationship a lasting affective impression left upon the viewer and carried with them in the media figure's absence.

Parasocial Phenomena and Identification

David C. Giles (2002) also completed a detailed review of the topic and proposes conceptual clarifications for use in further research. Giles (2002) untangles the amalgamation of parasocial phenomena with other psychological theories: most prominently identification. Giles (2002) draws on the work of Cohen (1999), Rubin (1981), Rosengren and Windahl (1972), and Feilitzen and Linné (1975) to consider the ways PSI is different from identification, which may play a part in PSI, but is a separate principle (Giles 2002). PSI can involve identification, which can be described as "the sharing of perspective," but users "may still engage in PSI without sharing perspective" (Giles 2002) – the two are different processes, though not mutually exclusive.

Categories of Parasocial Phenomena

Giles (2002) also makes an important distinction regarding the types of figures which facilitate PSI and PSR by creating three categories used to differentiate between them. The category of "first-order PSI" is comprised of media figures such as talk show hosts that project an authentic persona and "[address] the user directly"; "second-order PSI" is inhabited by representations of fictional characters played by actors, and "third-order PSI" consists of "fantasy or cartoon figures who have no real-life counterpart" (Giles 2002). Giles (2002) situates these categories on a continuum ranging from social to parasocial: a "one-on-one meeting with a media figure" that has real life social implications is at one end of the spectrum, while at the other is third-order PSI in which a real-life encounter or relationship with the figure is "impossible" as they are entirely fictional.

Applications in Game Studies

There have been few video-game-specific studies relating to PSI, and researchers who use PSI tend to lapse into similar patterns of amalgamation and conceptual confusion to those described above. Nass and Moon (2000) conducted a study which observed how users "mindlessly apply social rules and expectations to computers" in a paper which seems to explore a kind of PSI, without terming it as such, and Klimmt et al. (2009) mention PSI with regard to video games but focus on identification. Studies which consider PSI in relation to players' avatars are by far the most common in Game Studies: Chung et al. (2007) investigated the "influence of avatar creation on attitude towards avatar, empathy, presence, and parasocial interaction of female non-game users"; Banks and Bowman (2016) examined the relationship of the player to their avatar based on "along a continuum of non-social to parasocial to fully social," integrating a parasocial approach they term "character attachment" with a social approach they describe as "player-avatar relationships [PAR]"; and Jin and Park (2009) conducted a study examining the relationship between players' feeling of "self-presence" in a video game as mediated via their avatar, using PSI as a loose means of describing "players' interpersonal involvement with their avatar."

There are two particularly notable contributions to PSI discourse which both further develop the concept and contribute meaningfully to the use of PSI in Game Studies research: from Tilo Hartmann (2008) and Katrine Kavli (2012). Hartmann's (2008) paper acknowledges that digital media has the capability of facilitating more complex PSI than the mass media figures Horton and Richard Wohl (1956) describe and resituates the theory for the study of new media in general. Meanwhile, Kavli considers parasocial phenomena with a tighter focus on PSI with digital entities.

Paracommunication and Mediated Communication

Hartmann (2008) proposes key amendments to the schema, primarily based on the differing level of reciprocity that video games can offer, which old media cannot, observing that the original theory "only focused on processes of character perception" and should be called "parasocial processing of media characters" to take into account the unilateral direction and simple nature of engagement with mass media figures. On the other hand, mediated interaction via interactive technology, such as video games, offers a different form of PSI which more closely resembles communication as they "build on mutual awareness and include symbolic behaviour" (Hartmann 2008). Hartmann (2008) calls this more reciprocal exchange, "paracommunication," broadening the definition to include "most types of mediated interpersonal communication," arguing that communication with real people via technological means is likely to have a parasocial element due to the nature of the platform. Hartmann (2008) argues that for parasocial communication to occur, new media figures should be both "sufficiently authentic and distant." Distance, here, refers to the "perceived social distance" between the user and the person, or character, they are interacting with and is best summarized as "the degree of conviction the user has that his or her behavioral expressions do or do not have an impact on the symbolic behaviour of the other." Hartmann (2008) proposes that users are more likely to engage in playful parasocial communications with entities if, based on their "individual interpretation of the social situation," they perceive the consequences as being minimal – the greater the perceived social distance, the greater the freedom of interaction. Hartmann (2008) gives multiple examples to illustrate this point, arguing that video chat facilitates a level of paracommunication as some of the consequences of conversation are removed via the physical distance between participants. Similarly, virtual worlds such as Second Life (Linden Lab 2003) allow a degree of anonymity which may further reduce the perceived consequences of a user's actions (Hartmann 2008); therefore, paracommunication with an NPC, in most games, would rate as being playful – playful here meaning that there is a perceived lack, or low risk of, of real-life consequences.

Paracommunication and "Authenticity"

As well as being sufficiently distant, Hartmann (2008), like Giles (2002), argues that to encourage PSI, media figures should seem authentic. Hartmann's (2008) definition of realistic more thoroughly acknowledges the nuances of character design than Giles' (2002) more narrow definition. Hartmann (2008) suggests that "a character's behavior seems to be more important than its outer appearance"; authenticity is dependent on whether users "attribute a general intelligence and self-determination (i.e., an "intentional stance") to a character." The quality of being realistic, then, can be defined in terms which are less about the mimetic appearance of a character, and more about whether the character is "real" enough in emotional terms and capable of mediating affective engagement. Even if the media figures are distant and authentic enough to facilitate paracommunication, this may only occur if the user is receptive to it. Hartmann (2008) argues that users must be situated in "an involved mode" rather than an "analytical mode." "An involved mode" refers to narrative and affective receptivity, whereas an "analytical mode" creates an affective distance. In an involved mode, users, "at least momentarily—tend to believe in what they perceive."

Parasocial Phenomena and Video Games

Where Hartmann (2008) considers the application of PSI to technologically mediated communication in general, Kavli (2012) focuses specifically on how PSI "can be directly translated into the field of digital games" by analyzing different definitions of the term and considering its deployment in the field of Game Studies thus far. Kavli (2012) outlines the different digital entities which

may facilitate types of PSI: "bots" (NPCs), the "player avatar or character," and "other players' representations" (in a multiplayer game, for example). Kavli (2012) considers each of these digital entities using Horton and Wohl's (1956) original criteria. Unlike Hartmann (2008) who describes exchanges between players and NPCs as reciprocal, and categorizes them as paracommunication, Kavli (2012) observes that these interactions still have much in common with the mass media figures of Horton and Wohl's (1956) theory and notes that although players "may get the impression that the conversation involves [them] and the digital persona, the persona can only follow the static dialogue tree defined by a programmer." This, however, does not reduce the quality of the PSR for Kavli (2012) who notes that "some game characters succeed in establishing a relationship with a player that is so deep and heartfelt that the player wishes to break the boundaries between the digital and physical world in order to pursue the relationship" citing an article (Lah 2009) which documents the marriage of a man to a video game character.

Simulated Sociality

Kavli's further elucidation of PSI with NPCs need not negate Hartmann's (2008) work but clarifies it: If characters are authentic as Hartmann (2008) and Giles (2002) suggest, the reciprocity of the interactions need not be genuine but must have the appearance of being realistic. Game characters who offer third-order PSI may further blur the line between parasocial and social interaction, as the fictional nature of the characters denies players any possibility of meeting them, but may simulate a greater degree of reciprocity than PSI with a film or television character. When a viewer watches a personality program, their existence is generic and scripted interactions cannot change, whereas when they play a game, their icon and its programmed properties exist to the NPC, meaning that the NPC can address the icon directly and respond to them depending on the functionality of the software. At a basic level, NPCs will speak back when the player chooses to interact with them, and at a more complex level their responses may change depending on the player's selection of dialogue or relationship parameters. In a television show, hosts will continue speaking whether the viewer is there or not, decreasing the perceived authenticity of the interaction.

The Implications of Parasocial Phenomena

Throughout the reviewed literature, it is broadly agreed that PSI and PSR can serve as an extension of, and supplement for, healthy social interaction. Giles' (2002) model "presents PSI as an extension of normal social activity by considering shared and different qualities of social and parasocial encounters." Jarzyna (2020) has proposed that technology such as Netflix and social media paired with the COVID-19 pandemic has resulted in PSI serving as "social surrogacy" in which PSI is being used as a means to decrease the deficit in social needs and supplement real relationships by "filling social needs and decreasing loneliness," and Cohen (2014) states that relationships with fictional characters are "meaningful to us and in that sense they are very real." There is also research which suggests that "through parasocial relationships, people with low self-esteem can gain some of the benefits of real relationships without the fear of rejection" (Derrick et al. 2008). Although the reviewed literature (note Giles 2002; Kavli 2012 and Lah 2009) has identified risks of pathological behavior in which parasocial phenomena become detrimental to users' social lives – for example, when participants fail to identify when a relationship is parasocial and "believe that their PSI has been reciprocated by the media figure" (Giles 2002) – these cases are outliers and often connected to media figures who are real people. Such research findings across disciplines have provided a solid foundation from which to further explore parasocial phenomena, and such research could provide insight regarding the effects of utilizing technology to supplement social interaction, as well as exploring what such interactions can tell us about off-screen social dynamics.

Cross-References

- ▶ Game Design and Emotions: Analysis Models
- ▶ Narrative in Video Games

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Parasocial Relationships

- ▶ Parasocial Phenomena in Video Games

Participation

- ▶ Technologies for the Design Review Process

Particle System

- ▶ Game Engine

Party Game

- ▶ Among Us and Its Popularity During COVID-19 Pandemic

Path Planning

► Navigation Artificial Intelligence

PBL-Based Industry-Academia Game Development Education

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Synonyms

Constructionism; Constructivism; Inductive Learning; Situated Learning

Definitions

PBL (Project Based Learning)-based Industry-Academia Game Development Education is a pedagogical method for teaching essential theories, technical, and interpersonal skills of game development, by uniting the learner, game industry staff, and faculty from academia. The learners set a project, aiming to create an artifact to solve real-life problems, while the instructors in academia and industry both support the learners' progress. Throughout PBL, two institutes exchange knowledge, through lecturers, by providing the required tools and venue for game development, giving feedback, as well as by evaluating the completed projects to foster the future game developers.

Introduction

Following the rapid growth of video games and the widespread success of the gaming industry (Newzoo 2019) games research is becoming more diverse as academic communities and universities are responding to this change (Kultima 2015). Research publications, seminars, conferences, and associations on game related studies have been expanding on an international level (Mäyrä 2008). To this extent, some universities attempted to expand, share, and exchange teaching methods for game design inter-culturally (Engström et al. 2020; Pirker et al. 2016; Ruch 2019). Current academic game institutes offer courses aimed to prepare students for entering the creative, multimodal, interdisciplinary gaming industry, which requires not only knowledge of the technological aspects for game production but also competency for collaborative teamwork (Sillaots and Fiadotau 2018). Before this background, the importance of industry-academia collaboration is emphasized in terms of enhancing research and education for future game development (Godin et al. 2020), where students can earn practical training required in the industrial context (Mikami et al. 2010) and can share latest tools, technologies, and art techniques for current and future teaching and research (Kenwright 2016). Through such collaboration, the industry has a chance to headhunt good students (Bidarra et al. 2008). However, the difficulties of promoting such activities remain. Previous research has shown the difficulties in bridging these two institutions. For instance, problems of different priorities exists (Ficocelli 2007), and furthermore industries tend to be hard to reach for academic staffs (Parberry et al. 2005; Mikami et al. 2010). This results in a wide gap between industry and academia. As the industry tends to grow dramatically, it is challenging for academia to keep up and to reflecting the constantly changing cutting-edge requirements of the industry (Ritzhaupt 2009), which is gradually creating an expectation gap regarding the students' required skills to work in the industry (McGill 2009). However, the unique working environment in the industry is difficult to replicate in academia and the commonly used traditional approaches in university curricula fall short to meet the industry's demand (Hogue 2011). In order to overcome this problem, some companies are gradually opening their doors to collaborate with academia and have been successfully supporting game design and technology education through PBL (project-based learning) game development courses and projects. This

entry introduces how academia and industry can work together by integrating such PBL-based learning activities in their teaching methods. The PBL between industry and academia is constructed through considering multifaceted levels and this entry shows the essential 12 dimensions, which is meant to guide and assist in the decision-making process and to further discuss the possibilities of industry-academia collaboration for video games development and education.

Project Based Learning (PBL)

Project based learning is a student-centric and inductive pedagogical approach, in which the learning occurs as the students work on a project to tackle a real-life problem through investigation, discussion, and collaboration with others. This approach reflects the theory of constructionism, as the learners benefit from social interactions and sharing throughout the process of creating an artifact (Papert and Harel 1991) as well as situated learning (Wertsch 1985), which states the learning in context of practice in the learning process, internalizing knowledge through activities supported by mentoring. The base of this approach goes back to the beginning of the twentieth century, as John Dewey introduced such hands-on learning methods through *Learning by Doing* (Dewey 1986). There are essential components of projects practiced in the PBL, (1) the project requires an open-ended question or a problem created by the learners themselves or teachers (however, they shouldn't be constrained) and (2) the activities result in the form of artifacts, such as products, presentations, or any kind of presentable form at the end (Blumenfeld et al. 1991). In contrast to the traditional top-down deductive teaching method, the instructor takes the role as a facilitator during the PBL, providing resources, guidance, and instruction (Barrows and Tamblyn 1980), as well as feedback (Larmer and Mergendoller 2010). PBL is effective when it involves active learning, is goal-orientated, practice-based, contextualized, and interactive between teaching and/learning, as well as when it maintains the students' motivation and the impact of PBL affects students personal growth and achievements, including critical thinking, problem solving, communication, self-management, project management, and collaboration skills, which is transferable in today's rapidly changing and complex reality (Buck Institute for Education 2019). For game development and education, PBL approaches have gained attention in the field of computer science. Researchers/instructors attempted to integrate a PBL activity in traditional curricula, as students can thereby learn practical skills in the context of a real-life working situation and also earn life-long skills at the same time (Pirker et al. 2016). To this extent, creating games has been a popular method to realize PBL-based education, as the practice and process of game creation itself has been acknowledged as an efficient way to learn and practice multidisciplinary skills through collaborative learning (teamwork and communication) (Agterbos et al. 2019). Creating games awake students' learning motivation by enhancing autonomous learning in nature (Wu and Wang 2012). Instructors related to the field of game development have blended PBL-based project activities into their teaching. For example, PBL activities in academia have been combined with classroom lectures as an essential capstone in their courses (Zagal and Sharp 2011). Long-term PBL-based game development projects, longer than one semester, are introduced in some universities in a form of a thesis or graduation project to earn a degree in the field of game development (Mikami et al. 2010; Kenwright 2016). To realize the PBL blended with real-life experiences of the industry, game developers, technical staffs, executives, and industry researchers have been cooperating with academia. Referring to previous research, the following section introduces how academia and industry can construct a PBL-based education together by considering twelve essential dimensions.

12 Dimensions of Industry-Academia PBL

Categorizing previous works and courses on game development for higher education involves

PBL-based learning with collaboration of industry and academia. The following 12 major dimensions and their subsequent elements are essential components to determine a collaborative course on creating games (See Table 1):

Environment

Where students are taught about game related knowledge, where students work on game creation as group work, as well as where student-instructor interaction occurs differs depending on the physical setting of the learning/working environment. Most PBL activities are organized along with traditional classroom-based lectures in university. Some projects are carried out in a hybrid form: integrating both spaces of university and the industry, as the students conduct on-site team work in the company and development activities at faculty labs (Zajc and Starcic 2017). In other cases, online communication methods are integrated. For example, a Japanese mobile game company, Cygames, Inc. and the University of Skvde combined cyber and physical spaces to educate students from Japan and Europe, as students work on-site with asynchronous support from academia, as directors in the industry and academia supported the students' activity together (Sato et al. 2020). Ubisoft (2019) established a complete online-based game development training program with Concordia University, allowing the universities to adapt their program in courses by collaborating with the company.

Scale

The scale of the learning environment differs in terms of the geographical level of collaboration. Institutions tend to collaborate locally, which universities and companies in the same region partner to educate students. For example, Dutch game developers and Microsoft Netherlands supported the game development activities at the Delft University of Technology (Bidarra et al. 2008), EA and game developers in British Columbia partnered with the University of Victoria in USA (Estey et al. 2010), Disney, Sony, Nvidia, and AMD collaborated with University of Edinburg in Scotland (Kenwright 2016). Cygames, Inc. in Japan and University of Skvde in Sweden collaborated to support the game development projects of Swedish students in a rare cross-cultural collaboration (Sato et al. 2020).

Faculty Combination

As game development requires interdisciplinary developers, researchers introduced cross-disciplinary PBL activities to work on the project. The combination of faculties range from working on a project in a single faculty to collaborating with multiple faculties or universities, as students are required to form teams and assign roles by themselves to develop games in a real-world context (Shoop et al. 2019).

Modality

Types of industry-academia collaboration differ depending on when and how long the game development program last. The shortest is set to a 4-week project as the students went through the iterative cycle of game development, the longest is a 4-year game development course in which the students pursue a degree related to game development and technology (Mikami et al. 2010; Kenwright 2016). The most common type of the PBL-based projects are conducted per semester for 13–14 weeks, as instructors give lectures and students work on projects during as well as at the end of the semester as n assignment for final evaluation. PBL education can also take the form of an internship for approximately two months, as the students work on their projects collaborating with industry staffs (Sato et al. 2020).

Target Level

PBL-based learning is adaptable for a wide range of levels of students, from beginner courses teaching the fundamentals of game development to advanced contents, such as collaborating with the company to work on gaming technology. However as Yun et al. (2016) state, participating students should be on the same level to avoid elementary problems preventing the team work among students.

PBL-Based Industry-Academia Game Development Education, Table 1 12 Dimensions of industry-academia PBL-based game development education

Category	Type	Explanation
Environment	Academic institution	All activities are conducted at an academic institution
	Hybrid	Activities take place both in academic institution and the industry site
	Cyber-Physical	Learning environment integrates cyber space for communication and physical space for hands-on activities
	Online	Students learn game development know-how through online-based education
Scale	Local	The education is conducted in a particular single region with participants in a monolingual environment
	Global	The education is conducted in a global setting with participants from different regions in a multilingual situation
Faculty combination	Single	Project is conducted with members of one single faculty
	Internal collaboration	Students from different faculties studying in the same institute participate in the course to learn game development
	External collaboration	Two or more academic institutes studying different disciplines collaborate with each other
Modality	Project	PBL projects are conducted within a month
	Internship	A mid-term project conducted for 2–3 months
	Courses	Academic courses for game development range from short (13–16 weeks), middle (1–2 years) to long terms (4 years)
Target level	Beginner	PBL is targeted to teach a group of freshmen or sophomores (first to second year students).
	Intermediate	The group includes juniors and seniors
	Advanced	Projects are conducted by senior students mixed with graduate school students
Pedagogical focus	Game design and research	The course is focused on teaching the holistic process of game creation and production mostly centered in the field of Computer Science
	Game tech. and research	Courses are tailored to learn gaming technologies as well as engineering
Learning approach	Top-down	This approach examines completed games and reverse engineers to work on the individual elements
	Bottom-up	This approach first examines the concepts and game components separately and then begin to construct games and tools
Goal	Multidisciplinary	The course is aimed to experience, learn or collaborating with the diverse required skills in game development
	Soft-skills	These include necessary skills for team working to complete a game, such as collaboration, communication, and plan management
	Technology	The course is aimed to research specific techniques for game development, such as programming and other artwork
	Iteration/Agile	Students are expected to learn the iterated cycle of game development beginning from planning, prototyping and user tests
	Meaningful design	The aim is to develop a game for real-life use by applying user centered design techniques
Assessment	Summative	The final outcomes of the students' activity are evaluated to measure their learning
	Formative	Instructors and learners evaluate the progress of assignments or projects and give feedback towards the completion of the project
Role of industry	Instructor	Industry staff contributes to education as lecturer, mentor, mission provider for PBL or project evaluator for final assessments
	Environment provider	Industry shares their working office environment and offer equipment support to students

(continued)

PBL-Based Industry-Academia Game Development Education, Table 1 (continued)

Category	Type	Explanation
	Project collaborator	Academia and industry work together through collaborative research projects, sometimes involving students' thesis activities
	Program co-funder	Industry works with academia to establish an educational course to foster students
Communication method	Physical	Industry and academia communicate in a physical space, such as office meetings or lectures and contests provided at universities
	Cyber	Instructors from industry and academia as well as students communicate with each other through an online communication platform
Feedback	Student-Student	Peer review and feedback are given between students
	Student-Instructor	Instructors in academia and/or industry review students' progress through reports or meetings and give feedback to students' individual or group work

Pedagogical Focus

There are diverse aspects of what the teachers aim to teach through PBL. This can be largely categorized into two major categories: game design and research, or game technique and research. The former involves a focus on teaching from artworks in game development (Parberry et al. 2005), critically analyzing game elements (Whitehead 2008), learning the SCRUM/agile development cycle through pitching, prototype development and user testing (Bidarra et al. 2008; Shoop et al. 2019; Schoenau-Fog et al. 2019), experiencing or preparing for the real-life working environment in the gaming industry (Zajc and Starcic 2017; Estey et al. 2010), potentially in a cross-cultural context (Sato et al. 2020), as well as acquiring competitive behavior and entrepreneurship (Yun et al. 2016; Hogue et al. 2011). The latter focuses on teaching the technical aspects of creating games, such as obtaining specific professional skills required to be a programmer, 3D artists, technical artist or sound artist, and management skills involving engineering (Mikami et al. 2015).

Learning Approach for Game Development

Lecturers' approaches towards PBL-based game creation and learning can be divided into (1) top-down and (2) bottom-up approaches. In the top-down model, students examine completed games and reverse engineers them and understand the details of what composes a game. (2) The bottom-up approach requires students the practice of research, critical analysis, brainstorming, and improvisation techniques to as they are thought how to create a game (Kenwright 2016). In top-down approaches, some lectures are gamified, as the students learn game design and its structure by completing missions in an originally developed game (Ubisoft 2019; Parberry et al. 2005) and complete a game creation project at the end. The bottom-up approach involves learning through problem solving in the form of iterative collaborative group works, by following the form of game production, which is to conceptualize, develop, and playtest a game (Schoenau-Fog et al. 2019). Regardless of the major approaches, unique styles of teaching are combined with the development activity, such as game competitions (Yun et al. 2016; Parberry et al. 2005; Whitehead 2008) as well as peer evaluation (Estey et al. 2010) and presentation at game shows (Mikami et al. 2010). Hogue et al. (2011) conducted a workshop, in which students worked on holistic game production by developing games, user testing, business plan, marketing plan, and pitch presentations including the creation of a game trailer, for which the industry members took part in the evaluation. In terms of lecturer support, one-on-one frequent support from lecturers and mentors are noted throughout some projects, as the members from industry and academia both plays a role to guide the students to complete their game (Sato et al. 2020; Shoop et al. 2019; Zajc and Starcic 2017).

Goal

PBL-based game development courses have multiple goals of the following by learning the theory and practice of game development: (1) inter-/multidisciplinary skills, as game creation requires group work across different disciplines (Yun et al. 2016); (2) industry-relevant competency, which is not only aimed at the students achieving technical know-how of game development but also soft-skills, such as collaboration, critical-thinking, communication, management skills, and to give and receive critiques from others, as well as adapting to existing codes in the industry (Estey et al. 2010) and research and development skills (Mikami et al. 2010); (3) Agile/SCRUM and iteration, related also to industry competence, this process of software development is set as a pedagogical goal, as it aims to provide the students with contextual knowledge and exposes them to the importance of iterative learning loops, such as failure and reflection (Shoop et al. 2019); (4) User oriented development, as this step is common in the practice of the game development cycle, students go through the iteration of user testing and development, aiming to create a meaningful game for real-life use (Schoenau-Fog et al. 2019); (5) Entrepreneurship, game development courses in schools oriented to foster entrepreneurship also aim to teach students the skills of business and entrepreneurship in the games industry, teaching them skills of beginning a start-up company (Yun et al. 2016).

Student Assessment

The performance of students is assessed through summative or formative assessment methods or a combination thereof. Most projects take the summative assessment approach as the lecturers grade the final product: the artifacts, such as games and presentations, are created and submitted at the end of the course for evaluation. The formative assessment focuses on the students progress, through daily reflections of the learners or peer-to-peer review activities. The online course by Ubisoft (2019) provides several online learner analytic tools to keep track of students' performance. On the other hand, instructors can analyze texts produced by students and instructors in the form of self-review reports and feedback by utilizing natural language processing (Sato et al. 2020), to see how the students' activity and behavior changed throughout the PBL-based practice.

Role of Industry

As there are several combinations of pedagogical foci, approaches, and goals, the way of how the industry can be involved in the academic projects share similar models among different PBL-based educations: (1) The role as an instructor: the most frequent role of the industry is to provide students with the motivation and vision to work in real-life as lecturers (Yun et al. 2016; Parberry et al. 2005) and mentors/guide (Sato et al. 2020; Shoop et al. 2019; Zajc and Starcic 2017) for game development projects. Industry members are also invited to evaluate the outcomes of the students as Hogue et al. (2011) affirm that developers evaluating the final projects ensure higher quality and motivation as well as an opportunity to provide further feedback to the students. It also becomes an opportunity for the industry to acknowledge the skills of students (Schoenau-Fog et al. 2019; Bidarra et al. 2008). (2) The role as a provider: The industry opens their office to welcome students for internships (Sato et al. 2020) or as project work space (Zajc and Starcic 2017) as the students can experience the development in context of a real-life working environment. However, this requires careful planning between academia and industry as there is a difficulty of reflecting the student's work in the industry to the students' academic assignment (Sato et al. 2020). (3) Industry can work with the academia through professional collaborative research, where students work on research projects with the industry. In such collaborations, the industry offers support such as access to tools (hardware and software) and technological equipment. In such cases, the industry is involved as a co-founder of the game development courses at academia and further involved as a steering committee to design the game development course in academia (Mikami et al. 2010; Kenwright 2016), which enables the faculty to access information of new technology, insights, and trends of the rapid game industry.

Communication Method

The communication between industry, academia, and students takes place either online by utilizing communication platforms or in physical spaces. Cases of the three groups sharing a mutual communication space are seldom. Students and faculty can contact the industry through final presentations at the university, or in contrary, the students only have direct contact to the industry as they earn feedback. In terms of global communication and game development, the three groups can establish a TRIAD education model utilizing an online communication space, enabling a transparent and asynchronous communication to guide the students throughout their PBL project between industry-academia in a cross-cultural environment (Sato et al. 2020).

Feedback Source

Feedback in PBL is provided by faculty, industry, and students (peers). Emphasizing the efficiency of feedback in order to completing a game in a semester course, Yun et al. (2016) mention the effect of weekly mentoring to guide the students so that they will not be overambitious about their game development, consulting the students by determining what game components should be prioritized and designating milestones. Estey et al. (2010) emphasizes intensive peer-review activities, as the students assess written reviews on playtests and pitches, as the author claims that this helps the students getting acquainted with evaluation activities in the industry. The industry also provides feedback to the students' project, which not only helps the learners improve their skills on game development techniques but also learn how to review game design ideas by transferring techniques of plus/deltas, fast track postmortems, and sprint planning (Shoop et al. 2019) as well as to collaborate and communicate with the staffs from different positions and cultural backgrounds (Sato et al. 2020).

Cross-References

- ▶ Design Framework for Learning to Support Industry 4.0
- ▶ Game Development Leadership Tips

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Pedagogy

► ROP-Skill System: Model in Serious Games for Universities

Peer-to-Peer Gaming

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Synonyms

Multiplayer Online Game, MOG; Distributed Virtual Environment, DVE; Massively Multi-player Online Games, MMOG; Peer-to-Peer, P2P; Area of Interest, AOI

Definition

The term "peer-to-peer gaming" refers to all those mechanisms and techniques aimed at supporting a multiplayer, synchronous, and interactive networked game by using the computational resources of the players themselves.

Peer-to-Peer Gaming

Computer gaming greatly profited from the worldwide availability of the Internet in the mid-1990s and the consequent popularization of multiplayer online games (MOGs). A very popular genre of MOGs are massively multiplayer online games (MMOGs), which are large-scale applications supporting a large amount of players worldwide concurrently sharing a real-time virtual environment. MMOGs are naturally organized as a centralized client/server architecture: a main server maintains and shares the synchronized state of the game, whereas client players connect to the server to interact with the virtual environment and with each other. This imposes most of the load on the centralized server that, in a fraction of a second, has to receive requests from players, resolve conflicts to maintain consistency, update the game state, and send back the updated state to players. Furthermore, servers need to be maintained and operated according to the maximum peak load and have constraints of computational power, and network traffic concentrates in data centers.

For these reasons, decentralized alternatives to the centralized/server architectures (Ricci and Carlini 2012) raised a lot of interest among research and industry communities. Decentralized architectures are supported by a network of computational resources geographically distributed, rather than a large centralized server. A common characteristic of many decentralized proposals in the field is the application of peer-to-peer (P2P) principles and technologies for the management of the operations of the gaming platform. The main idea is to exploit computing and network resources of players to alleviate the load on centralized servers.

Nodes are connected to each other by one or more *P2P overlays* decentralizing and distributing core server operations, including the management of the game state and the multicast of messages. In principle, P2P-based gaming gives concrete advantages with respect to centralized approaches (Yahyavi and Kemme 2013). It requires a minimal fixed infrastructure to be operated. It is inherently scalable, as the available resources increase with the number of players. Moreover, these properties come with marginal or no costs for the game operator.

The use of P2P in gaming applications presents several differences with respect to other popular P2P applications, such as file-sharing. One notable difference is related to the content search. In a game, the interest of a player is often localized to only a certain set of events, whereas in file-sharing the desired content may possibly reside on any node of the network. Also, especially in multiplayer games, latency should be minimized in order to maximize interactivity, while it is no important in file-sharing applications.

Challenges

The application of P2P techniques naturally makes game architectures more complex and stems a number of challenges.

Due to their intrinsic distributed nature, every P2P game employs a certain level of replication of the virtual word state among peer resources. Replication is required essentially for two reasons. First it is mandatory for the definition of virtual environment: each participant must have its own copy of the state. Second, it is necessary to guarantee robustness and availability such that if a peer responsible for a piece of the state fails, another can take its place. If not properly addressed, inconsistencies lead to divergence on the game state, which in turn results in three major drawbacks (Delaney et al. 2006; Mauve 2000): (i) *divergence*, user experiences visual artifacts, (ii) *causality violation*, the actions are executed in wrong order, (iii) *expectation violation*, the user interacts with an inconsistent world. Further, especially in competitive games, inconsistencies can favor a participant with respect to the other, resulting in an unfair environment. In practice, when relying on best effort network, such as the Internet, strong consistency is hard to maintain due to the unpredictable latency and jitters. Therefore, client-side predictions are normally employed to avoid strong consistency in favor of an eventually consistent model. For example, local-lag and timewarp are *pessimistic* approaches that (Mauve et al. 2004) force an equal update delay to all replicas that reduce the inconsistencies. Conversely, Dead Reckoning (Pantel and Wolf 2002) is an *optimistic* approach in which each replica estimates the position of objects for a time interval, before finally synchronize with the other replicas. Another aspect that affects consistency regards the inherent unreliability of peer resources, i.e., they can leave the network voluntarily or abruptly, which might happen with short or without notice. This requires the DVEs to employ additional mechanisms for repairing the network and back up the game state.

Additionally, players' resources can be very heterogeneous in terms of computation capabilities, network, storage, and geographical positions. This heterogeneity has to be managed in order to exploit the right resource and avoid overloading. In fact, players interacting with each other and the surrounding virtual environment impose much load on the communication infrastructure, which can grow quadratically with the number of players (Nae et al. 2008). Further, load is intrinsically unbalanced as certain areas of the virtual world (i.e., hotspots) generate more load than the others. An overloaded peer resource managing a part of the world might deliver the events to the players with considerable delay, in fact compromising players' experience.

Finally, interest management refers to all those activities that are aimed to resolve a core but yet complicated problem in P2P games: for each player, to find the minimal subset of game entities (i.e., its *area of interest* (AOI)), that needs to be kept up-to-date. To find a proper AOI it is necessary to provide a smooth gaming experience and minimize resources utilization. An AOI too large can require more resources (especially network) than those available, while an AOI too small can fail to provide a good sense of interaction; either way it results in a degraded playing experience. It is worth noticing that interest management is a challenge also in centralized approaches, but it is exacerbated in decentralized contexts due to the partial knowledge of a peer node of the whole system.

Research in P2P Gaming

Research efforts toward P2P gaming are generally categorized into two broad families according on how they organized the overlay network that connects the players: *structured* and *unstructured*. In structured P2P DVEs (Bharambe et al. 2008; Kavalionak et al. 2015; Knutsson et al. 2004; Varvello et al. 2009), the overlay is defined according to a deterministic protocol that guarantees specific properties on the routing length and content-search performances. Popular structured overlays are Distributed Hash Tables (DHTs) such as Chord (Stoica et al. 2001) and Pastry (Rowstron and Druschel 2001). As far as concerns

interest management, DHTs guarantee $O(\log n)$ (with n being the number of nodes in the DHT) hoping to find any object in the virtual world but at the price of relatively high maintenance costs and limited adaptability of the overlay. Regarding consistency management, DHTs usually employ efficient and robust self-repairing mechanisms to provide robustness, which have been proven to be resilient to node failures even when a relatively large fraction of the nodes fail at the same time (Bharambe et al. 2008; Kavalionak et al. 2015).

In unstructured P2P DVEs, overlays lack a defined structure and are built relying on probabilistic mechanisms (as in gossip-based solutions (Carlini et al. 2012; Scholtes et al. 2008)) or according to the proximity of the peers in the virtual world (as in Voronoi-based solutions (Hu et al. 2006; Ricci et al. 2011)). Gossip overlay eventually converges to an overlay connecting those peers that are "close" according to some factor (e.g., share the same interest in a portion of the virtual world). Voronoi overlay is built by partitioning the virtual world into a Voronoi diagram (Aurenhammer 1991) and then connecting the peers accordingly (e.g., by creating a Delaunay overlay (Ricci et al. 2011)). Unstructured P2P overlays adapt quickly to sudden and unpredictable situations in the virtual worlds and are inexpensive to build and maintain. However, interest management in such networks is often done in a probabilistic manner and without strong guarantees on content retrieval. Consistency is usually managed by employing aggressive (and usually computationally costly) redundancy mechanisms, such as flooding or content replication. Regarding load balancing, DVEs based on Voronoi offer an inherent mechanism to distribute the load, as the Voronoi spatial partitioning naturally assigns regions to the peers. Finally, several approaches exploit a combination of structured and unstructured P2P overlays and are referred to as *hybrid* P2P-based DVEs (Buyukkaya et al. 2009; Kienzle et al. 2009; Yu and Vuong 2005).

Regardless of the overlay network structure (or lack of), normally the game world is divided into regions, with each peer assigned to manage one more regions. Some approaches delegate the management of the regions to any peer (Knutsson et al. 2004; Ricci et al. 2011), whereas other approaches consider a specific subset of peer (i.e., the *super peers*). Typically super peers are chosen for their hardware and bandwidth capabilities (Kim et al. 2004), either statically or by performing some kind of election mechanisms (Carlini et al. 2013; Chan et al. 2007).

Conclusion

From the perspective of research, P2P gaming has been a very thriving research field, bringing important innovations that have affected also other contexts of distributed systems, especially for the mechanisms and solutions to exploit the computational resources of the user to support an application. Despite this, P2P gaming platform outside the research context has had mild success. Initial enterprises that commercialized pure P2P gaming platforms, such as Manic Networks or DemonWare, eventually changed their core business. The main reason behind this situation is the lack of control of the game from the game published/developer. This makes extremely hard to control cheating, the performance are too dependent on the network of the players, and it is not possible to offer the users other payed services.

Today, P2P gaming solutions are utilized blended together with centralized infrastructures, to retain a degree of control on the game by the publishers. P2P gaming is then limited to only support several communications and in cases where a peer works as the server for specific multiplayer matches. A notable gaming market in which P2P solutions are currently used is the mobile and portable consoles one, for example, by the Nintendo Switch. In such systems, cheating is more complicated than on personal computers, and it is possible to exploit the proximity of the players to smooth the game.

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Peer-to-Peer, P2P

► Peer-to-Peer Gaming

Pencils of Spheres in the Minkowski-Lorentz Spaces

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Synonyms

Determination of orthogonal pencils of spheres.

Definitions

Introduction of Minkowski-Lorentz spaces to simplify Euclidean two- or three-dimensional problems.

Introduction

The entry deals with the Minkowski-Lorentz spaces in connection with some computer graphics computations problems. The Minkowski space is equipped of the isotropic quadratic form based on:

$$Q\left(\vec{u}\right) = x^2 + y^2 + z^2 - (c \times t)^2$$

where $\vec{u}(x, y, z, t)$ and c the speed of the light. From an n-dimensional Euclidean space $\mathcal{E}_n$ one can define the $n + 2$-dimensional Minkowski-Lorentz spaces. The computer-aided design process calls circles, spheres, and their pencils. These are basic shapes in the two- or three-dimensional Euclidean space. Thus, pencils of Euclidean circles in $\mathcal{E}_2$ or spheres in $\mathcal{E}_n$ are considered as circles in the suitable Minkowski-Lorentz space making the computation easier as the quadratic equations are seen as linear equations. Any circle in the Minkowski-Lorentz space is seen as the intersection of the unit sphere and a plane passing through the origin. The same algorithm for Euclidean circles or Euclidean spheres applies. The entry points out pencils of circles with base points in the two-dimensional space. It shows how pencils of orthogonal spheres in the Euclidean space are easily computed in the Minkowski-Lorentz space.

Some other problems, using pencils of tangent spheres in the Minkowski-Lorentz space, can be recalled: from three contact conditions (a point and an oriented plane containing this point) (Langevin et al. 2014), a one-parameter family of Dupin cyclides tangent along a common curve can be determined (see (Langevin et al. 2014)); a Dupin cyclide principal patch (Martin 1982; Srinivas et al. 1996) can be computed (Garnier and Druoton 2013a; Garnier and Druoton 2013b).

This entry is organized as follows: section "Pencils of Oriented n – 1-Spheres in ε_n" deals with the oriented circles (resp. spheres) in the usual Euclidean plane (resp. space). In Section "Linear Pencil of 2-Spheres in $L_{4,1}$," the oriented circles or spheres are represented as circles in the Minkowski-Lorentz space. In Section "Pencils of Orthogonal Spheres," from a given pencil $\mathcal{P}_1$ of circles or spheres, an other pencil $\mathcal{P}_2$ of circles or spheres is computed, where each element of $\mathcal{P}_2$ is perpendicular to an element of $\mathcal{P}_1$. The last section draws some conclusion and proposes future works.

Pencils of Oriented n – 1-Spheres in ε_n

An n – 1-sphere S with center Ω and radius r generates two n – 1-spheres S^+ (with a positive radius $\rho = r$) and S^- (with a negative radius $\rho = -r$). The n – 1-sphere S^+ is such that the unit normal vector $\vec{N}$ at the point M is in the same direction than the vector $\overrightarrow{\Omega M}$. For the n – 1-sphere S^-, the unit normal vector $\vec{N}$ at the point M has

the direction opposite to the vector $\overrightarrow{\Omega M}$. Then, the authors have the same formula in the two cases

$$\overrightarrow{\Omega M} = \rho \vec{N}. \tag{1}$$

with $|\rho| = r$. The authors can define the power of a point.

Definition 1 *Power of a point M with respect to an n – 1-sphere*

Let S *be an oriented n – 1-sphere of center Ω and of (algebraic) radius ρ. Let M be a point of* $\mathcal{E}_n$.

The power of the point M with respect to the n – 1-sphere S is the following real number:

$$\chi_{\mathrm{S}}(M) = \Omega M^2 - \rho^2 \tag{2}$$

The number $\chi_{\mathrm{S}}(M)$ does not depend on the sign of the radius ρ. The points M of the n – 1-sphere S are characterized by $\chi_{\mathrm{S}}(M) = 0$. The points M belonging to the bounded part defined by S are characterized by $\chi_{\mathrm{S}}(M) < 0$. The other points M verify $\chi_{\mathrm{S}}(M) > 0$. This notion to two spheres can be generalized.

Definition 2 *Orthogonal spheres and relative power of two spheres*

For $i \in \{1, 2\}$, *let* S_i *be an n – 1-sphere of center* Ω_i *and of radius* ρ_i. *The relative power of the two spheres* S_1 *and* S_2 *is*

$$\chi_{\mathrm{S}_1,\mathrm{S}_2} = \Omega_1\,\Omega_2^2 - \rho_1^2 - \rho_2^2 \tag{3}$$

Moreover the n – 1-spheres S_1 *and* S_2 *are orthogonal if the authors have*

$$\chi_{\mathrm{S}_1,\mathrm{S}_2} = 0 \tag{4}$$

In fact, let A be a point of the non-empty set $\mathrm{S}_1 \cap \mathrm{S}_2$. The $n-1$ spheres S_1 and S_2 are orthogonal if $\Omega_1\Omega_2 A$ is a right-angled triangle and the segment $[\Omega_1\ \Omega_2]$ is the hypotenuse of $\Omega_1\Omega_2 A$. Using the power of a point with respect to a sphere, the authors can define a pencil of spheres.

Definition 3 *Pencil of spheres*

For $i \in \{1, 2\}$, *let* S_i *be an n – 1-sphere of center* Ω_i *and of radius* ρ_i *with* $\Omega_1 \neq \Omega_2$.

Let λ_1 *and* λ_2 *be two reals not both equal to zero.*

The pencil of n – 1-spheres defined by S_1 *and* S_2 *is the set, denoted* $\lambda_1\ \mathrm{S}_1 + \lambda_2\ \mathrm{S}_2$, *containing the points M which verify*

$$\lambda_1\ \chi_{\mathrm{S}_1}(M) + \lambda_2\ \chi_{\mathrm{S}_2}(M) = 0 \tag{5}$$

The Euclidean scalar product of $\overrightarrow{\mathcal{E}_n}$ is noted •. First, the particular case $\lambda_1 + \lambda_2 = 0$ is considered. In this case, if M belongs to $\lambda_1\ \mathrm{S}_1 - \lambda_1\ \mathrm{S}_2$, Eq. (5) becomes

$$\Omega_1 M^2 - \rho_1^2 - \Omega_2 M^2 + \rho_2^2 = 0 \tag{6}$$

which is equivalent to

$$\left(\overrightarrow{\Omega_1 M} - \overrightarrow{\Omega_2 M}\right) \bullet \left(\overrightarrow{\Omega_1 M} + \overrightarrow{\Omega_2 M}\right) = \rho_1^2 - \rho_2^2$$

which can be simplified into

$$\overrightarrow{\Omega_1\,\Omega_2} \bullet \overrightarrow{IM} = \frac{\rho_1^2 - \rho_2^2}{2} \tag{7}$$

where I is the midpoint of the segment $[\Omega_1\ \Omega_2]$. Let I_0 be the point of the line $(\Omega_1\ \Omega_2)$ defined by

$$\overline{II_0} = \frac{\rho_1^2 - \rho_2^2}{2\,\overline{\Omega_1\,\Omega_2}} \tag{8}$$

where $\overline{AB}$ designates the algebraic length of the vector $\overrightarrow{AB}$. Then, $\lambda_1\ \mathrm{S}_1 - \lambda_1\ \mathrm{S}_2$ is an oriented hyperplane passing through I_0 and its unit normal vector is $\frac{1}{\overline{\Omega_1\,\Omega_2}}\overrightarrow{\Omega_1\,\Omega_2}$ or $\frac{-1}{\overline{\Omega_1\,\Omega_2}}\overrightarrow{\Omega_1\,\Omega_2}$.

If $\lambda_1 + \lambda_2 \neq 0$ and if M is a point of $\lambda_1\ \mathrm{S}_1 + \lambda_2\ \mathrm{S}_2$, Eq. (5) becomes

$$\begin{aligned}&\lambda_1\left(\overrightarrow{\Omega_1\,\Omega_{12}} + \overrightarrow{\Omega_{12}M}\right)^2\\ &\quad + \lambda_2\left(\overrightarrow{\Omega_2\,\Omega_{12}} + \overrightarrow{\Omega_{12}M}\right)^2\\ &\quad = \lambda_1\,\rho_1^2 + \lambda_2\,\rho_2^2\end{aligned} \tag{9}$$

where Ω_{12} is the barycenter of the weighted points $(\Omega_1,\ \lambda_1)$ and $(\Omega_2,\ \lambda_2)$. Formula (9) can be transformed into

$$\overrightarrow{\Omega_{12}M^2} = -\frac{\lambda_1\left(\Omega_1\,\Omega_{12}^2 - \rho_1^2\right) + \lambda_2\left(\Omega_2\,\Omega_{12}^2 - \rho_2^2\right)}{\lambda_1 + \lambda_2} \tag{10}$$

which shows that the center of the $n-1$-sphere $\lambda_1\,\mathrm{S}_1 + \lambda_2\,\mathrm{S}_2$ is the point Ω_{12} whereas the radius of the aforementioned sphere is

$$\rho_{12} = \varepsilon\sqrt{-\frac{\lambda_1\left(\Omega_1\Omega_{12}^2 - \rho_1^2\right) + \lambda_2\left(\Omega_2\,\Omega_{12}^2 - \rho_2^2\right)}{\lambda_1 + \lambda_2}} \tag{11}$$

where ε belongs to $\{-1,1\}$. The authors can state.

Theorem 1 *For $i \in \{1,\ 2\}$, let S_i be an $n-1$-sphere of center Ω_i and of radius ρ_i with $\Omega_1 \neq \Omega_2$.*

Let λ_1 and λ_2 be two reals not both equal to zero defining a pencil of $n-1$-spheres $\lambda_1\,\mathrm{S}_1 + \lambda_2\,\mathrm{S}_2$. Then:

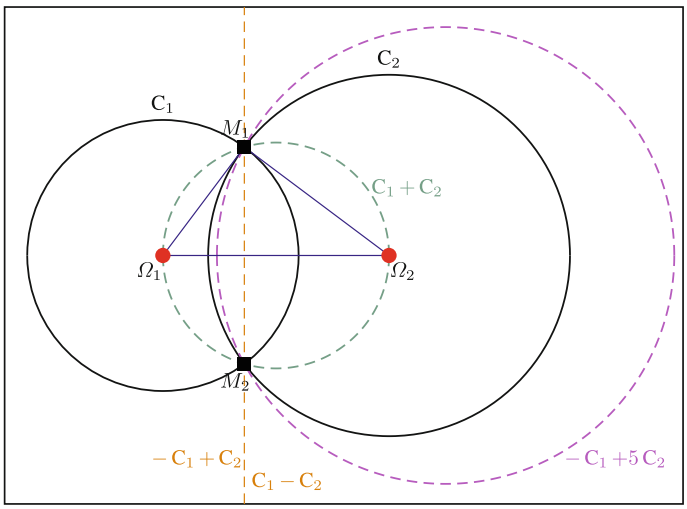
1. *If the Intersection of spheres S_1 and S_2 is a non-empty set (two points if $n = 2$, a circle if $n = 3$) C, then all the spheres (and the two oriented hyperplanes) contain the set C: the defined pencil is called a pencil with $n-2$-sphere, that is, base points if $n = 2$ and a base circle if $n = 3$,* Fig. 3a.
2. *If the spheres S_1 and S_2 are tangent at the point M_0, then all the spheres (and the two oriented hyperplanes) are tangent to S_1 and S_2 at M_0: the defined pencil is called a pencil of tangent spheres,* Fig. 3b.
3. *If the intersection of S_1 and S_2 is empty, there exist two points P_1 and P_2 on the line $(\Omega_1\ \Omega_2)$ such that the center of the sphere $\lambda_1\,\mathrm{S}_1 + \lambda_2\,\mathrm{S}_2$, $(\lambda_1 \neq -\lambda_2)$, belongs to $(\Omega_1\ \Omega_2)$ –] P_1, P_2 [: the pencil is called a pencil with limit points or a Poncelet pencil,* Fig. 3c.

Proof The proof is left to the reader and follows directly from the previous computations. ■

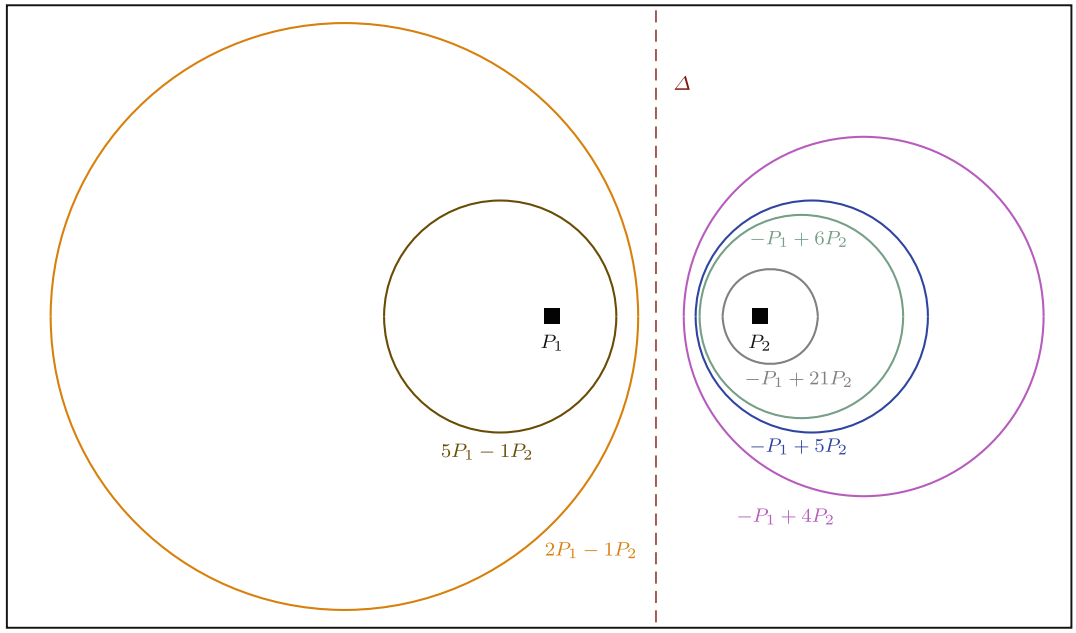
In $\mathcal{E}_2$, Fig. 1 shows a pencil of spheres with two base points. This pencil is computed from two orthogonal 1-spheres (i.e., circles), the hypotenuse of the right-angled triangle $\Omega_1\ \Omega_2\ M_1$ is the segment $[\Omega_1\ \Omega_2]$. The radii $[\Omega_1\ M_1]$ and $[\Omega_2\ M_1]$ are perpendicular.

Figure 2 shows a Poncelet pencil generated by two distinct points P_1 and P_2. Two oriented hyperplanes, the oriented perpendicular bisectors of the segment $[P_1\ P_2]$, belong to this pencil.

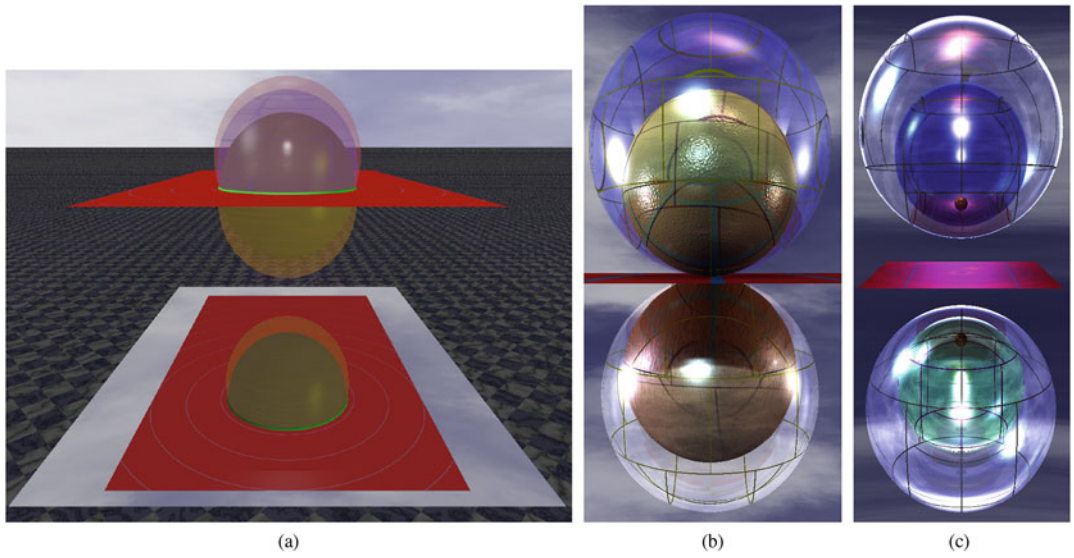
Figure 3 shows two pencils of 2-spheres in $\mathcal{E}_3$. In Fig. 3a, the pencil with a base circle is generated by two orthogonal 2-spheres: a hyperplane and a 2-sphere. The common circle is a great circle of the original 2-sphere. In Fig. 3b, the pencil is defined by two tangent spheres. In Fig. 3c, the Poncelet pencil is defined by two points.



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 1 Two orthogonal 1-spheres C_1 and C_2 generate a pencil of 1-spheres with base points M_1 and M_2 in $\mathcal{E}_2$. The line $(M_1\ M_2)$ defines two oriented hyperplanes $\mathrm{C}_1 - \mathrm{C}_2$ and $-\mathrm{C}_1 + \mathrm{C}_2$ belonging to this pencil



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 2 Two points P_1 and P_2 generate a Poncelet pencil of 1-spheres in $\mathcal{E}_2$. The line Δ is the perpendicular bisector of the segment $[P_1\ P_2]$ and defines two oriented hyperplanes $P_1 - P_2$ and $-P_1 + P_2$ of this pencil



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 3 Three types of 2-spheres pencils in $\mathcal{E}_3$. (**a**): a pencil of 2-spheres with base circle (in green) generated by two orthogonal sphere and hyperplane, (**b**): a pencil of tangent 2-spheres, (**c**): a Poncelet pencil

Pencils of Spheres in the Minkowski-Lorentz Spaces, Table 1 Definition of the three types of 2-planes in the Minkowski-Lorentz vector space $\overrightarrow{L_{n+1,1}}$ or in the Minkowski-Lorentz affine space $L_{n+1,1}$

Type	Two-dimensional plane $\vec{\mathcal{P}}$ or $\mathcal{P}$
Space-like	All the vectors of $\vec{\mathcal{P}}$ are space-like vectors
Time-like	Contain at least a time-like vector or exactly two non-collinear light-like ones
Light-like	Planes parallel to a tangent plane to the light cone C_l

Linear Pencil of 2-Spheres in $L_{4,1}$

A recall about the Minkowski-Lorentz space $L_{4,1}$ can be found in (Garnier et al. 2017; Garnier et al. 2019).

Section "Pencils of Oriented $n-1$-Spheres in $\mathcal{E}_n$" has shown that there exist three types of pencils of oriented $n-1$-spheres in $\mathcal{E}_n$, and there is a one-to-one relationship between the type of the pencil and the type of the 2-plane containing the aforementioned curve, Table 1. In the rest of the entry, the type of the planar curves which represents the one-parameter family of $n-1$-spheres depends on the type of the plane containing this curve.

Some properties can be stated:

Theorem 2 *Let C be the intersection between Λ^{n+1} and a two-dimensional affine plane $\mathcal{P}$ passing through Ω_{n+2}.*

- *The unit circle C looks like an ellipse and corresponds to a pencil of $n-1$-spheres with a base $n-2$-sphere,* Figs. 3a and 4a.
- *The unit circle C is the union of two parallel lines and corresponds to a pencil of tangent $n-1$-spheres,* Figs. 3b and 4b. *The point of tangency is defined by the direction of these light-like lines.*
- *The unit circle C looks like a hyperbola and corresponds to a Poncelet pencil of tangent $n-1$-spheres,* Figs. 3c and 4c.

Proof The following lemma is needed:

Lemma 1 *The representation of any pencil of $n-1$-spheres is the intersection between Λ^{n+1} and a two-dimensional affine plane $\mathcal{P}$ passing through O_{n+2}.*

Proof of Lemma 1 For $i \in \{1, 2\}$, let S_i be an $n-1$-sphere of center Ω_i and of radius ρ_i with $\Omega_1 \neq \Omega_2$. Let $\overrightarrow{\sigma_i}$ be the representation of the $n-1$-sphere S_i on Λ^{n+1}.

1/First case: $\lambda_1 + \lambda_2 = 0$

Without loss of generality, $\lambda_1 = 1 = -\lambda_2$ is used. For all point I_0, the previous relation leads to

$$\begin{cases} \overrightarrow{O_{n+2}\Omega_1}^2 = \overrightarrow{O_{n+2}I_0}^2 + 2\overrightarrow{O_{n+2}I_0} \bullet \overrightarrow{I_0\Omega_1} + \rho_1^2 \\ \overrightarrow{O_{n+2}\Omega_2}^2 = \overrightarrow{O_{n+2}I_0}^2 + 2\overrightarrow{O_{n+2}I_0} \bullet \overrightarrow{I_0\Omega_2} + \rho_2^2 \end{cases}$$

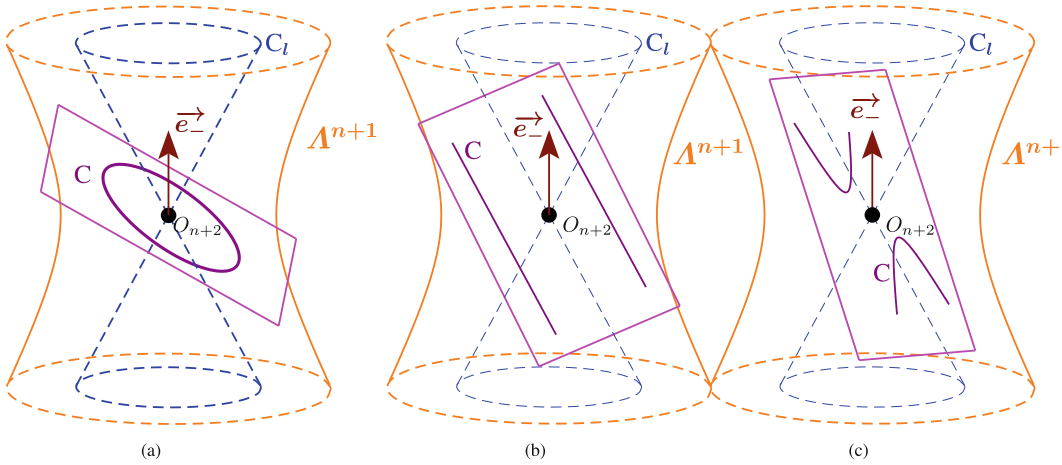
Then:

$$\begin{aligned} \frac{\rho_1}{\Omega_2\Omega_1}\overrightarrow{\sigma_1} - \frac{\rho_2}{\Omega_2\Omega_1}\overrightarrow{\sigma_2} &= \frac{1}{\Omega_2\Omega_1}\left(\overrightarrow{O_{n+2}\Omega_1} - \overrightarrow{O_{n+2}\Omega_2} + \frac{\left\|\overrightarrow{O_{n+2}\Omega_1}\right\|^2 - \rho_1^2 - \left\|\overrightarrow{O_{n+2}\Omega_2}\right\|^2 + \rho_2^2}{2}\overrightarrow{e_\infty}\right) \\ &= \frac{1}{\Omega_2\Omega_1}\overrightarrow{\Omega_2\Omega_1} + \frac{2\overrightarrow{O_{n+2}I_0} \bullet \left(\overrightarrow{I_0\Omega_1} - \overrightarrow{I_0\Omega_2}\right)}{2\,\Omega_2\Omega_1}\overrightarrow{e_\infty} \\ &= \frac{1}{\Omega_2\Omega_1}\overrightarrow{\Omega_2\Omega_1} + \left(\overrightarrow{O_{n+2}I_0} \bullet \frac{1}{\Omega_2\Omega_1}\overrightarrow{\Omega_2\Omega_1}\right)\overrightarrow{e_\infty} = \overrightarrow{\pi_1} \end{aligned}$$

and the representations $\overrightarrow{\pi_1}$ and $-\overrightarrow{\pi_1}$ of the two oriented hyperplanes of the pencil, $\overrightarrow{\sigma_1}$ and $\overrightarrow{\sigma_2}$ are co-planar.

2/Second case: $(\lambda_1 + \lambda_2)\,\lambda_1\,\lambda_2 \neq 0$

Without loss of generality, the relation $\lambda_2 = 1 - \lambda_1$ is used. The center Ω_{12} of the $n-1$-sphere



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 4 Three unit circles C which represent the three types of the pencils of $n-1$-spheres as intersection between the unit sphere Λ^{n+1} and a two-dimensional affine plane passing through O_{n+2}. (**a**): A pencil with base $n-2$-spheres, the type of the 2-plane is space-like, the curve looks like an ellipse. (**b**): A pencil of tangent $n-2$-spheres, the type of the 2-plane is light-like, the curve is the union of two lines. (**c**): A Poncelet pencil, the type of the 2-plane is time-like, the curve looks like an hyperbola

$\lambda_1 S_1 + (1-\lambda_1) S_2$ is the barycenter of the weighted points (Ω_1, λ_1) and $(\Omega_2, 1-\lambda_1)$. The radius of this $n-1$-sphere is given by Formula (11).

Let $\overrightarrow{\sigma_{12}}$ be the representation on Λ^{n+1} of the $n-1$-sphere $\lambda_1 S_1 + \lambda_2 S_2$ of the pencil of $n-1$-spheres generated by S_1 and S_2. Then

$$\overrightarrow{\sigma_{12}} = \frac{1}{\rho_{12}}\left(\overrightarrow{e_o} + \frac{\left\|\lambda_1\overrightarrow{O_{n+2}\Omega_1} + (1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right\|^2 - \rho_{12}^2}{2}\overrightarrow{e_\infty} + \lambda_1\overrightarrow{O_{n+2}\Omega_1} + (1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right) \tag{12}$$

The following relation

$$\rho_{12}\overrightarrow{\sigma_{12}} = \lambda_1\rho_1\overrightarrow{\sigma_1} + (1-\lambda_1)\rho_2\overrightarrow{\sigma_2} \tag{13}$$

must be proved.

The relation $\overrightarrow{e_o} = \lambda_1\overrightarrow{e_o} + (1-\lambda_1)\overrightarrow{e_o}$ leads to

$$\begin{aligned}\lambda_1\rho_1\overrightarrow{\sigma_1} + (1-\lambda_1)\rho_2\overrightarrow{\sigma_2} &= \overrightarrow{e_o} + \lambda_1\overrightarrow{O_{n+2}\Omega_1} + (1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2} \\ &+ \frac{\lambda_1\left(\left\|\overrightarrow{O_{n+2}\Omega_1}\right\|^2 - \rho_1^2\right) + (1-\lambda_1)\left(\left\|\overrightarrow{O_{n+2}\Omega_2}\right\|^2 - \rho_2^2\right)}{2}\overrightarrow{e_\infty}\end{aligned} \tag{14}$$

From Formulas (12) and (14), the following relation

$$\begin{aligned}\left\|\lambda_1\overrightarrow{O_{n+2}\Omega_1}+(1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right\|^2-\rho_{12}^2\\ =\lambda_1\left(\left\|\overrightarrow{O_{n+2}\Omega_1}\right\|^2-\rho_1^2\right)\\ +(1-\lambda_1)\left(\left\|\overrightarrow{O_{n+2}\Omega_2}\right\|^2+\rho_2^2\right)\end{aligned}\quad(15)$$

implies that Formula (13) is true. As

$$\begin{aligned}&\left\|\lambda_1\overrightarrow{O_{n+2}\Omega_1}+(1-\lambda_1)\overrightarrow{O_3\Omega_2}\right\|^2\\ &=\lambda_1^2\overrightarrow{O_{n+2}\Omega_1}^2+(1-\lambda_1)^2\overrightarrow{O_{n+2}\Omega_2}^2\\ &\quad+2\lambda_1(1-\lambda_1)\overrightarrow{O_{n+2}\Omega_1}\bullet\overrightarrow{O_{n+2}\Omega_2}\end{aligned}$$

the last step is the computation of $-\rho_{12}^2$:

$$\begin{aligned}-\rho_{12}^2&=\lambda_1\left(\left(\overrightarrow{\Omega_1O_{n+2}}+\overrightarrow{O_{n+2}\Omega_{12}}\right)^2-\rho_1^2\right)+(1-\lambda_1)\left(\left(\overrightarrow{\Omega_2O_{n+2}}+\overrightarrow{O_{n+2}\Omega_{12}}\right)^2-\rho_2^2\right)\\ &=\lambda_1\left(\overrightarrow{\Omega_1O_{n+2}}^2+\overrightarrow{O_{n+2}\Omega_{12}}^2+2\overrightarrow{\Omega_1O_{n+2}}\bullet\overrightarrow{O_{n+2}\Omega_{12}}-\rho_1^2\right)\\ &\quad+(1+\lambda_1)\left(\overrightarrow{\Omega_2O_{n+2}}^2+\overrightarrow{O_{n+2}\Omega_{12}}^2+2\overrightarrow{\Omega_2O_{n+2}}\bullet\overrightarrow{O_{n+2}\Omega_{12}}-\rho_2^2\right)\\ &=\lambda_1\left(\overrightarrow{\Omega_1O_{n+2}}^2-\rho_1^2\right)+(1-\lambda_1)\left(\overrightarrow{\Omega_2O_{n+2}}^2-\rho_2^2\right)+\overrightarrow{O_{n+2}\Omega_{12}}^2\\ &\quad+2\left(\lambda_1\overrightarrow{\Omega_1O_{n+2}}+(1-\lambda_1)\overrightarrow{\Omega_2O_{n+2}}\right)\bullet\overrightarrow{O_{n+2}\Omega_{12}}\end{aligned}$$

and the condition given in Formula (15) becomes

$$\begin{aligned}&\left\|\lambda_1\overrightarrow{O_{n+2}\Omega_1}+(1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right\|^2+\overrightarrow{O_{n+2}\Omega_{12}}^2\\ &\quad-2\left(\lambda_1\overrightarrow{O_{n+2}\Omega_1}+(1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right)\bullet\overrightarrow{O_{n+2}\Omega_{12}}\\ &\quad=0\end{aligned}$$

which can be simplified into

$$\begin{aligned}&\left\|\lambda_1\overrightarrow{O_{n+2}\Omega_1}+(1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right\|^2\\ &\quad-\left(\lambda_1\overrightarrow{O_{n+2}\Omega_1}+(1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right)\bullet\overrightarrow{O_{n+2}\Omega_{12}}\\ &\quad=0\end{aligned}$$

(Ω_{12} is the barycenter of the weighted points (Ω_1, λ_1) and $(\Omega_2, 1-\lambda_1)$) which can be simplified into

$$\begin{aligned}&\left\|\lambda_1\overrightarrow{O_{n+2}\Omega_1}+(1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right\|^2\\ &\quad-\left\|\lambda_1\overrightarrow{O_{n+2}\Omega_1}+(1-\lambda_1)\overrightarrow{O_{n+2}\Omega_2}\right\|^2\\ &\quad=0\end{aligned}$$

As this last relation is still true: the relation (13) is true too.

3/Conclusion: the vectors $\overrightarrow{\sigma_{12}}$, $\overrightarrow{\sigma_1}$, and $\overrightarrow{\sigma_2}$ are always co-planar. Moreover, if $\vec{\sigma}$ represents an $n-1$-sphere of the pencil, $-\vec{\sigma}$ represents the same geometrical $n-1$-sphere of the pencil, then O_{n+2} belongs to the 2-plane containing the points σ (The orientation of the two $n-1$-spheres change.).

□

Proof of the Theorem To prove the theorem, the number of light direction is determined.

1. If the pencil is a pencil with base $n-2$-spheres, all the $n-1$-spheres of this pencil are not degenerate, the type of the 2-plane is space-like.

2. If the pencil is a pencil of tangent $n-2$-spheres, one and only one of the $n-1$-spheres of this pencil is degenerate (the point of tangency), the type of the 2-plane is light-like.
3. If the pencil is a Poncelet pencil, two distinct $n-1$-spheres of this pencil are degenerate (the limit point), the type of the 2-plane is time-like.

■

The curves in Fig. 4 are unit circle (for the Lorentz form) of center O_{n+2} because any point c which represents a nondegenerate $n-1$-sphere of a pencil verifies $\overrightarrow{O_{n+2}\sigma}^2 = 1$. The equations of these curves are given in the next subsections.

Equation of a Pencil with Base $n-2$-Sphere

Let us remark that if $n=2$, the $n-2$-sphere is the union of two points M_1 and M_2, the center of this $n-2$-sphere is the midpoint of the segment $[M_1 M_2]$, the radius of this $n-2$-sphere is $\frac{M_1M_2}{2}$. The general equation of this type of pencil can be given.

Proposition 1 *Let C be a geometrical $n-2$-sphere of $\mathcal{E}_n$ of center Ω_1 and of (positive) radius r_1.*

*Let S_1 be an $n-1$-sphere of center Ω_1 and of radius ρ_1 (*i.e.*, $|\rho_1| = r_1$).*

Let $\mathcal{P}_1$ be an oriented hyperplane containing the $n-2$-sphere C.

Let $\overrightarrow{\sigma_1}$ (resp. $\overrightarrow{\pi_1}$) be the representation of S_1 (resp. $\mathcal{P}_1$) on Λ^{n+1}.

The parametric equation of the pencil of $n-1$-spheres with base C is

$$\begin{aligned}\overrightarrow{\sigma(t)} &= \overrightarrow{O_{n+2}\sigma(t)} \\ &= \cos(t)\ \overrightarrow{\sigma_1} + \sin(t)\,\overrightarrow{\pi_1}, t \in \mathbb{R}\end{aligned} \tag{16}$$

Proof Let us recall that $\mathcal{P}_1$ and S_1 are orthogonal, that is, $\overrightarrow{\sigma_1}^{\blacksquare}\overrightarrow{\pi_1} = 0$.

From theorem 2, an $n-1$-sphere of this pencil is linear combination of two $n-1$-spheres of this pencil. So, from Formula (16), an $n-1$-sphere $\sigma(t)$ verifies

$$\begin{aligned}\overrightarrow{O_{n+2}\sigma(t)}^2 &= \left(\cos(t)\,\overrightarrow{\sigma_1} + \sin(t)\,\overrightarrow{\pi_1}\right)^2 = \cos^2(t)\underbrace{\overrightarrow{\sigma_1}^2}_{=1} + \sin^2(t)\underbrace{\overrightarrow{\pi_1}^2}_{=1} + 2\cos(t)\,\sin(t)\underbrace{\overrightarrow{\sigma_1}^{\blacksquare}\overrightarrow{\pi_1}}_{=0} \\ &= \cos^2(t) + \sin^2(t) = 1\end{aligned}$$

and the point $\sigma(t)$ belongs to an unit circle, of center O_{n+2}, of Λ^{n+1}. Moreover

$$\left\{\begin{array}{l|rcl}\overrightarrow{O_{n+2}\sigma(t)}^{\blacksquare}\overrightarrow{\sigma_1} & = & |\cos(t)| \le 1 \\ \overrightarrow{O_{n+2}\sigma(t)}^{\blacksquare}\overrightarrow{\pi_1} & = & |\sin(t)| \le 1\end{array}\right.$$

which proves that $\sigma(t)$ cuts $C = \mathrm{S}_1 \cap \mathcal{P}_1$. ■

Formula (16) leads to $\overrightarrow{\sigma(0)} = \overrightarrow{\sigma_1}$ and $\frac{\overrightarrow{d\sigma(0)}}{dt} = \overrightarrow{\pi_1}$: the vector $\overrightarrow{\pi_1}$ is the unit vector which is tangent to the circle at the point $\sigma(0)$.

An example of the representation of this type of curve using rational quadratic Bézier curves and mass points is given, more general results about mass points and rational quadratic Bézier curves can be found in (Garnier and Bécar 2017; Garnier and Bécar 2016; Garnier et al. 2017).

Let C be the circle of $\mathcal{E}_3$, in the plane $\mathcal{P}: z=0$, of center O_3 and of radius 2. The oriented sphere S_1^- of center O_3 and of radius -2 and the plane $\mathcal{P}_1^+$ oriented by the normal vector $\vec{k}$ are chosen. The representation of S_1^- is σ_1 defined by

$$\begin{aligned}\overrightarrow{O_5\sigma_1} &= -\frac{1}{2}\left(\overrightarrow{e_0} + \overrightarrow{O_3O_3} + \frac{1}{2}\left(\overrightarrow{O_3O_3} - (-2)^2\right)\overrightarrow{e_\infty}\right) \\ &= -\frac{1}{2}\left(\overrightarrow{e_0} - 2\overrightarrow{e_\infty}\right)\end{aligned}$$

whereas the representation of $\mathcal{P}_1$ is π_1 defined by

$$\overrightarrow{O_5\pi_1} = \vec{k} + \left(\overrightarrow{O_3O_3} \bullet \vec{k}\right)\overrightarrow{e_\infty} = \vec{k}$$

One can see that

$$\overrightarrow{O_5\sigma_\blacksquare}\,\overrightarrow{O_5\pi} = 0$$

On the space of spheres Λ^4, the pencil is represented by two rational quadratic Bézier curves using mass points, the first and last control points are the points σ and $-\sigma$ of the Minkowski-Lorentz affine space $L_{4,1}$ whereas the intermediate control point $\overrightarrow{\pi_1}$ is a unit space-like vector of the Minkowski-Lorentz vector space $\overrightarrow{L_{4,1}}$. In Formula (16), $t \in [0, \pi]$ and then

$$\overrightarrow{O_5\sigma(\vartheta)} = \frac{1-\vartheta^2}{1+\vartheta^2}\overrightarrow{O_5\sigma_1} + \frac{2\vartheta}{1+\vartheta^2}\overrightarrow{\pi_1} \qquad (17)$$

with $\vartheta \in \overline{\mathbb{R}}$ and $\vartheta \in \overline{\mathbb{R}^+}$ to obtain a semi-circle. To use Bezier curve, the parameter must belong to [0,1], the numerical function h is defined by⟧

$$h(u) = \frac{u}{1-u} \qquad (18)$$

and $h([0,1]) = \overline{\mathbb{R}^+}$. Let us recall the quadratic Bernstein polynomial

$$B_i(t) = \frac{2!}{i!(2-i)!}(1-t)^{2-i}t^i$$

where i belongs to {0,1,2}. Using mass points, a rational quadratic Bézier curve is defined by weighted point $(P_i,\ \omega_i)$ and/or vectors $\left(\vec{P}_i, \omega_i = 0\right)$. Let us define the two sets

$$\begin{cases} I = \{i \in \ [\![0,1]\!] \ \mid \omega_i \neq 0\} \\ J = \{i \in \ [\![0,1]\!] \ \mid \omega_i = 0\} \end{cases}$$

and the denominator

$$\omega_f(t) = \sum_{i\in I}\omega_i \times B_i(t)$$

Let t_0 in [0, 1]. If $\omega_f(t_0) \neq 0$, for any point O, the element of the Bézier curve is a weighted point $M(t_0)$ defined by

$$\overrightarrow{OM(t_0)} = \frac{1}{\omega_f(t_0)}\sum_{i\in I}\omega_i B_i(t_0)\overrightarrow{OP_i} + \frac{1}{\omega_f(t_0)}\sum_{i\in J}B_i(t_0)\overrightarrow{P_i} \qquad (19)$$

and if $\omega_f(t_0) = 0$, the element of the Bézier curve is the vector $\overrightarrow{u(t_0)}$ defined by

$$\overrightarrow{u(t_0)} = \sum_{i\in I}\omega_i B_i(t_0)\overrightarrow{OP_i} + \sum_{i\in J}B_i(t_0)\overrightarrow{P_i} \qquad (20)$$

Formulas (17) and (18) lead to

$$\begin{aligned}
\overrightarrow{O_{n+2}\sigma(h(u))} &= \frac{1-\left(\frac{u}{1-u}\right)^2}{1+\left(\frac{u}{1-u}\right)^2}\overrightarrow{O_5\sigma_1} + \frac{2\frac{u}{1-u}}{1+\left(\frac{u}{1-u}\right)^2}\overrightarrow{\pi_1} \\
&= \frac{1-2u+u^2-u^2}{1-2u+u^2+u^2}\overrightarrow{O_5\sigma_1} + \frac{2u(1-u)}{1-2u+u^2+u^2}\overrightarrow{\pi_1} \\
&= \frac{1}{B_0(u)+B_2(u)}\left((B_0(u)-B_2(u))\overrightarrow{O_5\sigma_1} + B_1(u)\overrightarrow{\pi_1}\right) \\
&= \frac{1}{B_0(u)+B_2(u)}\left(B_0(u)\overrightarrow{O_5\sigma_1} + B_1(u)\overrightarrow{\pi_1} + B_2(u)\overrightarrow{O_5\sigma_-}\right)
\end{aligned}$$

P

Pencils of Spheres in the Minkowski-Lorentz Spaces, Table 2 Spheres of a pencil of 2-spheres with base circle

Value	Point $\sigma(t)$	Sphere in $\mathcal{E}_3$
$t=0$	$\left(-\frac{1}{2};0;0;0;1\right)=-\frac{1}{2}\left(1;0;0;0;\frac{1}{2}\left(-(-2)^2\right)\right)$	Center: (0; 0; 0), radius − 2
$t=\frac{1}{4}$	$\left(-\frac{2}{5};0;0;-\frac{3}{5};\frac{4}{5}\right)=\frac{1}{-\frac{3}{2}}\left(1;0;0;-\frac{3}{2};-2\right)$	Center : $\left(0;0;-\frac{3}{2}\right)$, radius $-\frac{5}{2}$
$t=\frac{1}{2}$	(0; 0; 0; 1; 0)	Point (0; 0; 0), normal vector $\vec{k}$
$t=\frac{3}{4}$	$\left(\frac{2}{5};0;0;\frac{3}{5};-\frac{4}{5}\right)=\frac{1}{\frac{3}{2}}\left(1;0;0;\frac{3}{2};-2\right)$	Center : $\left(0;0;\frac{3}{2}\right)$, radius $\frac{5}{2}$
$t=1$	$\left(\frac{1}{2};0;0;0;1\right)=\frac{1}{2}\left(1;0;0;0;\frac{1}{2}\left(-(2)^2\right)\right)$	Center: (0; 0; 0), radius 2

where σ_- is the symmetrical of σ_1 with respect to O_5. Then, the control points of the Bézier curve are $(\sigma_1, 1)$, $\left(\overrightarrow{\pi_1};0\right)$, and $(\sigma_-, 1)$. The control points of the Bézier curve which model the second semi-circle are $(\sigma_1, 1)$, $\left(-\overrightarrow{\pi_1};0\right)$, and $(\sigma_-, 1)$. After some simplifications, $\sigma(t)$ is defined by

$$\overrightarrow{O_5\sigma(t)}=\frac{1}{1-2t+t^2}\left(\frac{2t-1}{2}\overrightarrow{e_0}+2t(1-t)\vec{k}+(1-2t)\overrightarrow{e_\infty}\right)$$

and some 2-spheres are drawn, see Table 2 and Fig. 5.

For example, $t=\frac{1}{4}$ leads to $\frac{1}{2}\left(\left(-\frac{3}{2}\right)^2-\left(-\frac{5}{2}\right)^2\right)=-2$. In fact, if $t\neq\frac{1}{2}$, the radius of the corresponding $n-1$-sphere is

$$\frac{1}{1-2t+2t^2}\times\frac{2t-1}{2}=\frac{1}{(1-t)^2+t^2}\times\frac{2t-1}{2}$$

and the change of the orientation of the spheres is obtained for $t=\frac{1}{2}$, that is, when an $n-1$-sphere of the pencil is an hyperplane.

Equations of a Poncelet Pencil

In the same way as in the previous paragraph, a parameterization of a Poncelet Pencil on Λ^{n+1} can be given.

Proposition 2 *Let M_0 and M_2 be two limit points of a Poncelet pencil of $n-1$-spheres $S(t)$.*

Let $\overrightarrow{m_0}$ and $\overrightarrow{m_2}$ the light-like vectors in the Minkowski-Lorentz vector space $\overrightarrow{L_{n+1,1}}$ which represent the points M_0 and M_2. A parametric equation of a Poncelet pencil is

$$\overrightarrow{\sigma(t)}=\overrightarrow{O_{n+2}\sigma(t)}=t\frac{1}{M_2M_0}\overrightarrow{m_1}-\frac{1}{t}\frac{1}{M_2M_0}\overrightarrow{m_2},t\in\mathbb{R}^* \quad (21)$$

or

$$\overrightarrow{\sigma_{hyp}(t)}=\overrightarrow{O_{n+2}\sigma_{hyp}(t)}=\frac{1}{\cos(t)}\frac{1}{M_2M_0}\left(\overrightarrow{m_0}-\overrightarrow{m_2}\right)+\frac{\tan(t)}{M_2M_0}\left(\overrightarrow{m_0}+\overrightarrow{m_2}\right) \quad (22)$$

where t belongs to $[0,\ 2\pi]-\left\{\frac{\pi}{2},\frac{3\pi}{2}\right\}$, the type of the vector $\overrightarrow{m_0}-\overrightarrow{m_2}$ (resp. $\overrightarrow{m_0}+\overrightarrow{m_2}$) is space-like (resp. time-like).

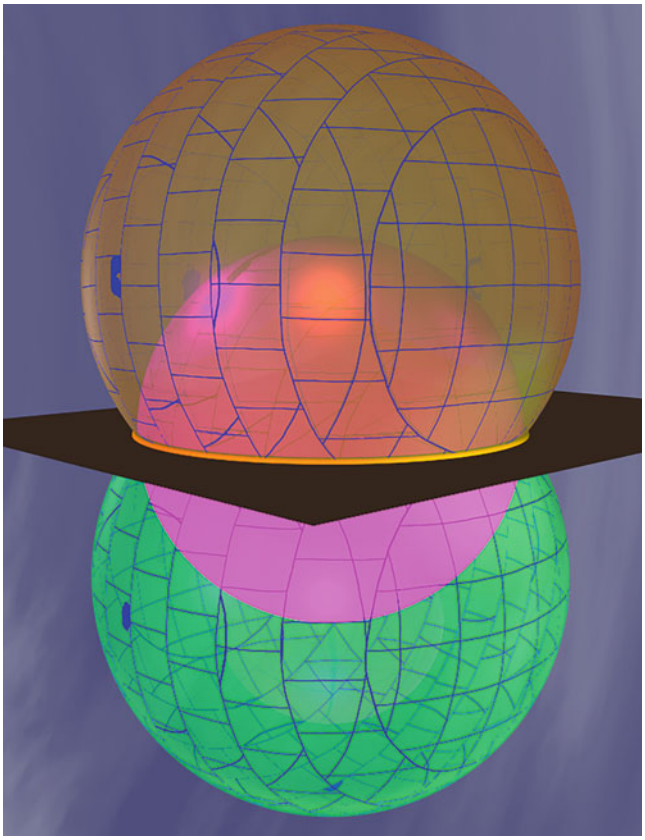
Proof Using Theorem 2, any sphere of this pencil is a linear combination of the two light-like vectors $\overrightarrow{m_0}$ and $\overrightarrow{m_2}$ with

$$\overrightarrow{m_0}=\overrightarrow{e_o}+\overrightarrow{M_0}+\frac{1}{2}\left\|\overrightarrow{M_0}\right\|^2\overrightarrow{e_\infty}$$

and

$$\overrightarrow{m_2}=\overrightarrow{e_o}+\overrightarrow{M_2}+\frac{1}{2}\left\|\overrightarrow{M_2}\right\|^2\overrightarrow{e_\infty}$$

Moreover:



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 5 Some spheres of a pencil of spheres with base circle modeled on the space of spheres Λ^4 by a rational quadratic Bézier curve representing a semicircle

$$\overrightarrow{m_0} \blacksquare \overrightarrow{m_2} = \left(\overrightarrow{e_o} + \overrightarrow{O_3M_0} + \frac{1}{2}\left\|\overrightarrow{O_3M_0}\right\|^2 \overrightarrow{e_\infty}\right) \blacksquare \left(\overrightarrow{e_o} + \overrightarrow{O_3M_2} + \frac{1}{2}\left\|\overrightarrow{O_3M_2}\right\|^2 \overrightarrow{e_\infty}\right)$$
$$= \overrightarrow{O_3M_0} \bullet \overrightarrow{O_3M_2} - \frac{1}{2}\overrightarrow{O_3M_0}^2 - \frac{1}{2}\overrightarrow{O_3M_2}^2 = -\frac{1}{2}\left(\overrightarrow{O_3M_0} - \overrightarrow{O_3M_2}\right)^2 = -\frac{1}{2}\overrightarrow{M_2M_0}^2$$

The plane defined by the curve, Formula (21) or (22), contains two light-like vectors, so the type of this plane is time-like. The last step consists in showing that $\sigma(t)$ and $\sigma_{hyp}(t)$ belong to Λ^{n+1}. As

$$\vec{\sigma}(t)^2 = \left(t\frac{1}{M_2M_0}\overrightarrow{m_1} - \frac{1}{t}\frac{1}{M_2M_0}\overrightarrow{m_2}\right)^2 = \frac{1}{M_2M_1^2}\left(t^2\overrightarrow{m_0}^2 - 2\overrightarrow{m_0} \blacksquare \overrightarrow{m_2} + \frac{1}{t^2}\overrightarrow{m_2}^2\right)$$
$$= \frac{-2}{M_2M_0^2}\left(-\frac{1}{2}\overrightarrow{M_2M_0}^2\right) = 1.$$

$\sigma(t)$ belongs to Λ^{n+1}. □

Concerning the second equation, the relations

$$\left(\overrightarrow{m_0} + \overrightarrow{m_2}\right)^2 = \overrightarrow{m_0}^2 + 2\,\overrightarrow{m_0} \blacksquare \overrightarrow{m_2} + \overrightarrow{m_2}^2 = -\overrightarrow{M_2M_0}^2 < 0 \tag{23}$$

and

$$\left(\overrightarrow{m_0} - \overrightarrow{m_2}\right)^2 = \overrightarrow{m_0}^2 - 2\,\overrightarrow{m_0} \blacksquare \overrightarrow{m_2} + \overrightarrow{m_2}^2 = \overrightarrow{M_2M_0}^2 > 0 \tag{24}$$

lead to

$$\begin{aligned}\overrightarrow{\sigma_{hyp}}(t)^2 &= \left(\frac{1}{\cos(t)}\frac{1}{M_2M_0}\left(\overrightarrow{m_0} - \overrightarrow{m_2}\right) + \mathrm{sh}(t)\frac{1}{M_2M_0}\left(\overrightarrow{m_0} + \overrightarrow{m_2}\right)\right)^2 \\ &= \frac{1}{M_2M_0^2}\left(\frac{1}{\cos^2(t)}\overrightarrow{M_2M_0}^2 - \tan^2(t)\overrightarrow{M_2M_0}^2\right) + \frac{2}{M_2M_0^2}\frac{\tan(t)}{\cos(t)}\left(\underbrace{\overrightarrow{m_0}^2}_{=0} - \underbrace{\overrightarrow{m_2}^2}_{=0}\right) \\ &= \frac{1}{\cos^2(t)} - \tan^2(t) = 1\end{aligned}$$

and $\sigma_{hyp}(t)$ belongs to Λ^{n+1}. ■

From Formula (21) and using Formula (18), the expression of the Bézier curve is

$$\begin{aligned}\overrightarrow{O_{n+2}\sigma(h(u))} &= \frac{u}{1-u}\frac{1}{M_2M_0}\overrightarrow{m_0} - \frac{1-u}{u}\frac{1}{M_2M_0}\overrightarrow{m_2} \\ &= \frac{u^2}{u(1-u)}\frac{1}{M_2M_0}\overrightarrow{m_0} - \frac{(1-u)^2}{u(1-u)}\frac{1}{M_2M_0}\overrightarrow{m_2} \\ &= \frac{1}{2u(1-u)}\left((1-u)^2\frac{2}{M_2M_0}\overrightarrow{m_2} + 2u(1-u)\overrightarrow{O_{n+2}O_{n+2}} - u^2\frac{2}{M_2M_0}\overrightarrow{m_0}\right) \\ &= \frac{1}{\frac{M_2M_0}{2}2u(1-u)}\left(B_0(u)\overrightarrow{m_2} + \frac{M_2M_0}{2}B_1(u)\overrightarrow{O_{n+2}O_{n+2}} - B_2(u)\overrightarrow{m_0}\right)\end{aligned}$$

and the control mass points of this rational quadratic Bézier curve are $\left(\overrightarrow{m_2}, 0\right)$, $\left(O_{n+2}, \frac{M_2M_0}{2}\right)$, and $\left(-\overrightarrow{m_0}, 0\right)$. This Bézier curve represents a branch of a unit circle which looks like a rectangular hyperbola. The second branch is modeled by a rational quadratic Bézier curve of control mass points $\left(\overrightarrow{m_2}, 0\right)$, $\left(O_{n+2}, -\frac{M_2M_0}{2}\right)$ and $\left(-\overrightarrow{m_0}, 0\right)$. In (Garnier and Bécar 2017; Garnier and Bécar 2016), a branch of a hyperbola in the usual Euclidean affine space is modeled by a rational quadratic Bézier curve of control mass points $\left(\overrightarrow{W_0}, 0\right)$, (Ω_1, ω_1), and $\left(\overrightarrow{W_2}, 0\right)$, where $\overrightarrow{W_0}$ and $\overrightarrow{W_2}$ are unit vectors and Ω is the center of the aforementioned hyperbola. If the norm of

these vectors is changed, the value of the weight ω_1 is modified. In this case in the Minkowski-Lorentz space, the second control point is the center of the circle, but the other control mass points are light-like vectors and then

$$\forall \lambda \in \mathbb{R}^*, \quad \left(\lambda \overrightarrow{m_0}\right)^2 = \left(\lambda \overrightarrow{m_2}\right)^2 = \overrightarrow{m_0}^2 = \overrightarrow{m_2}^2 = 0$$

it is not possible to distinguish two parallel light-like vector using their norms. So, the following condition is introduced.

Condition 1

If a light-like vector $\overrightarrow{m_0}$ is not $\overrightarrow{e_\infty}$, it represents a point of the Euclidean affine space $\mathcal{E}_n$ and then its first component is equal to 1.

The rational quadratic Bézier expression is simplified

$$\begin{aligned}\overrightarrow{O_{n+2}\sigma(u)} &= \frac{B_0(u)}{\omega_1 B_1(u)}\left(\overrightarrow{e_0} + \overrightarrow{O_3M_0} + \frac{\overrightarrow{M_0}^2}{2}\overrightarrow{e_\infty}\right) - \frac{B_2(t)}{\omega_1 B_1(t)}\left(\overrightarrow{e_0} + \overrightarrow{O_3M_2} + \frac{\overrightarrow{M_2}^2}{2}\overrightarrow{e_\infty}\right)\\ &= \frac{1}{\omega_1 B_1(t)}\left((B_0(t) - B_2(t))\overrightarrow{e_0} + \left(B_0(t)\frac{\overrightarrow{M_0}^2}{2} - B_2(t)\frac{\overrightarrow{M_2}^2}{2}\right)\overrightarrow{e_\infty} + B_0(t)\overrightarrow{O_3M_0} - B_2(t)\overrightarrow{O_3M_2}\right)\end{aligned}$$

Let us consider the two points $M_0(-2; 0; 0)$ and M_2 (2; 0; 0) of $\mathcal{E}_3$. Let us choose $\omega_1 = 2$. As $\overrightarrow{O_3M_2} = -\overrightarrow{O_3M_0}$ and $O_3M_0 = 2$, $\sigma(t)$ is defined by

$$\overrightarrow{O_5\sigma(t)} = \frac{1-2t}{4t(1-t)}\left(\overrightarrow{e_0} + 2\overrightarrow{e_\infty}\right) + \frac{1-2t+2t^2}{4t(1-t)}\overrightarrow{O_3M_0}$$

and some spheres are computed in Table 3 and drawn in Fig. 6. For $t = 0$ (resp. $t = 1$), the vector $\overrightarrow{m_0}$ (resp. $\overrightarrow{m_2}$) which represents the point M_0 (resp. M_2) are computed.

Equation of a Pencil of Tangent $n-1$-Spheres

Let us recall the following formula computed in (Garnier et al. 2019)

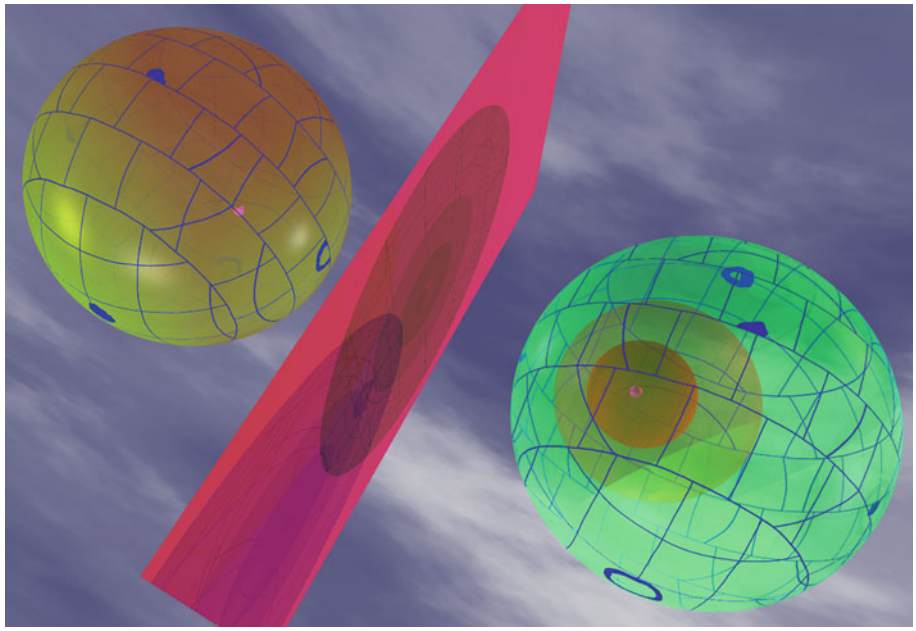
$$\overrightarrow{\sigma_1} \blacksquare \overrightarrow{\sigma_2} = -\frac{1}{2\rho_1\rho_2}\chi_{S_1,S_2} \tag{25}$$

where χ_{S_1,S_2} is obtained from Formula (3).

Let σ_1 and σ_2 be the representations of two $n-1$-spheres of $\mathcal{E}_n$ such that the spheres are tangent at the point M. Formulas (1) and (25) lead to

Pencils of Spheres in the Minkowski-Lorentz Spaces, Table 3 Spheres of a Poncelet pencil defined by two points in $\mathcal{E}_3$

Value	Point $\sigma(t)$	Sphere in $\mathcal{E}_3$
$t = \frac{1}{10}$	$\left(\frac{20}{9}; -\frac{41}{9}; 0; 0; \frac{40}{9}\right) = \frac{1}{\frac{9}{20}}\left(1; -\frac{41}{20}; 0; 0; 2\right)$	Center: $\left(-\frac{41}{20}; 0; 0\right)$, radius $\frac{9}{20}$
$t = \frac{1}{6}$	$\left(\frac{6}{5}; -\frac{13}{5}; 0; 0\frac{12}{5}\right) = \frac{1}{\frac{5}{6}}\left(1; -\frac{13}{6}; 0; 0; 2\right)$	Center: $\left(-\frac{13}{6}; 0; 0\right)$, radius $\frac{5}{6}$
$t = \frac{1}{4}$	$\left(\frac{2}{3}; -\frac{5}{3}; 0; 0; \frac{4}{3}\right) = \frac{1}{\frac{3}{2}}\left(1; -\frac{5}{2}; 0; 0; 2\right)$	Center: $\left(-\frac{5}{2}; 0; 0\right)$, radius $\frac{3}{2}$
$t = \frac{1}{2}$	(0 1 −1; 0; 0; 0)	Point (0; 0; 0), normal vector $-\vec{\imath}$
$t = \frac{3}{4}$	$\left(-\frac{2}{3}; -\frac{5}{3}; 0; 0; -\frac{4}{3}\right) = \frac{1}{-\frac{3}{2}}\left(1; \frac{5}{2}; 0; 0; 2\right)$	Center: $\left(\frac{5}{2}; 0; 0\right)$, radius $-\frac{3}{2}$



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 6 Some 2-spheres of a Poncelet pencil in $\mathcal{E}_3$ modeled by a rational quadratic Bézier curve with control mass points in the Minkowski-Lorentz space

$$\begin{aligned}\overrightarrow{\sigma_1}\blacksquare\,\overrightarrow{\sigma_1} &= -\frac{1}{2\rho_1\rho_2}\chi_{S_1,S_2} = \frac{1}{2\rho_1\rho_2}\left(-\overrightarrow{\Omega_2\Omega_1}^2+\rho_1^2+\rho_2^2\right) = \frac{1}{2\rho_1\rho_2}\left(-\left(\overrightarrow{\Omega_2M}+\overrightarrow{M\Omega_1}\right)^2+\rho_1^2+\rho_2^2\right)\\ &= \frac{1}{2\rho_1\rho_2}\left(-\overrightarrow{\Omega_2M}^2-2\overrightarrow{\Omega_2M}\blacksquare\,\overrightarrow{M\Omega_1}-\overrightarrow{M\Omega_2}^2+\rho_1^2+\rho_2^2\right)\\ &= \frac{1}{2\rho_1\rho_2}\left(-\rho_2^2\underbrace{\overrightarrow{N_2}^2}_{=1}+2\rho_1\rho_2\,\overrightarrow{N_2}\blacksquare\,\overrightarrow{N_1}-\rho_1^2\underbrace{\overrightarrow{N_1}^2}_{=1}+\rho_1^2+\rho_2^2\right) = \overrightarrow{N_2}\blacksquare\,\overrightarrow{N_1}\in\{-1,1\}\end{aligned}$$

Moreover, the relation

$$\begin{aligned}\overrightarrow{\sigma_1\sigma_2}^2 &= \left(\overrightarrow{\sigma_1O_{n+2}}+\overrightarrow{O_{n+2}\sigma_2}\right)^2 = \left(\overrightarrow{\sigma_2}-\overrightarrow{\sigma_1}\right)^2\\ &= \overrightarrow{\sigma_1}^2-2\overrightarrow{\sigma_1}\blacksquare\,\overrightarrow{\sigma_2}+\overrightarrow{\sigma_2}^2 = 2\left(1-\overrightarrow{\sigma_1}\blacksquare\,\overrightarrow{\sigma_2}\right)\end{aligned} \tag{26}$$

permits to state

Proposition 3 *Let S_1 and S_2 be two oriented $n-1$-spheres of the Euclidean affine space $\mathcal{E}_n$.*

Let $\overrightarrow{\sigma_1}$ (resp. $\overrightarrow{\sigma_2}$) be the representation of S_1 (resp. S_2) on Λ^{n+1}.

The $n-1$-spheres S_1 and S_2, having the same orientation, are tangent if and only if

$$\overrightarrow{\sigma_1\sigma_2}^2 = 0$$

The important result is that, on Λ^{n+1}, **a light line (called light ray too) is the representation of tangent oriented $n-1$-spheres, having the same orientation, at the same point. The direction of the vector $\overrightarrow{\sigma_1\sigma_2}$ gives the point of tangency between the two $n-1$-spheres** and we can give the equation of a pencil of tangent $n-1$-spheres:

Proposition 4 *Let S_1 be an $n-1$-sphere and M_1 a point on S_1.*

Let $\overrightarrow{\sigma_1}$ (resp. $\overrightarrow{m_1}$) be the representation of S_1 (resp. M_1) on Λ^{n+1}.

The parametric equation of the representation of the pencil of $n-1$-spheres tangent to the sphere S_1 is

$$\overrightarrow{\sigma(t)} = \overrightarrow{O_{n+2}\sigma(t)} = \varepsilon\overrightarrow{\sigma_1} + t\overrightarrow{m_1}, t \in \mathbb{R} \qquad (27)$$

where ε belongs to $\{-1, 1\}$.

Pencils of Orthogonal Spheres

In this section, from a given pencil $\mathcal{P}_1$ of spheres, a pencil $\mathcal{P}_2$ of spheres is computed such as any sphere of the pencil $\mathcal{P}_1$ is orthogonal to all the spheres of the pencil $\mathcal{P}_2$. Using Minkowski-Lorentz space, the solution of this problem is very simple: each pencil is defined by a 2-plane $\mathcal{P}_i, i \in \{1, 2\}$ passing through the point O_{n+2}, it is enough that the 2-planes $\mathcal{P}_1$ and $\mathcal{P}_2$ are perpendicular.

If $n = 2$, there is no choice, see Table 4, whereas if $n = 3$, there is a degree of freedom using an line Δ orthogonal to the 2-planes $\mathcal{P}_1$ and $\mathcal{P}_2$, see Table 5.

For $i \in \{1, 2\}$, the reader can note that if the center of the conic $\mathcal{P}_i \cap \Lambda^4$ is $\Omega_i \neq O_5$ with the two following conditions:

$$\begin{cases} \overrightarrow{O_5\Omega_1}^2 \neq 0 \\ \overrightarrow{O_5\Omega_2} = \dfrac{1}{\overrightarrow{O_5\Omega_1}^2}\overrightarrow{O_5\Omega_1} \end{cases} \qquad (28)$$

Table 5 gives the properties of Dupin cyclides where base circle (resp1 Poncelet) (resp2 tangent spheres) is replaced by ring (resp. horned or spindle) (resp2 one-singularity spindle or singly horned). One can note the conditions given in Formula (28) lead to

$$\overrightarrow{O_5\Omega_2}\cdot\overrightarrow{O_5\Omega_1} = 1$$

Example with a Pencil of Line Passing Through a Point in $\mathcal{E}_2$

Let $\mathcal{P}_t$ be the pencil of lines defined by the point Ω_0 (1, 1) and the normal vector $\vec{N}(\cos(t), \sin(t))$. The representation of the pencil $\mathcal{P}_t$ in the Minkowski-Lorentz space $L_{3,1}$ is

$$\vec{\Pi}_0(t)\,(0, \cos(t), \sin(t), \cos(t) + \sin(t))$$

As $\vec{\Pi}_0(0)\,(0, 1, 0, 1)$ and $\vec{\Pi}_0\left(\frac{\pi}{2}\right)(0, 0, 1, 1)$, the computation

Pencils of Spheres in the Minkowski-Lorentz Spaces, Table 4 Pencils of orthogonal spheres in $\mathcal{E}_2$

Type of $\mathcal{P}_1$	Type of $\mathcal{P}_1$	Type of $\mathcal{P}_2$	Type of $\mathcal{P}_2$
Base circle	Space-like	Time-light	Poncelet
Poncelet	Time-light	Space-like	Base circle
Tangent spheres	Light-like	Light-like	Tangent spheres

Pencils of Spheres in the Minkowski-Lorentz Spaces, Table 5 Pencils of orthogonal spheres in $\mathcal{E}_3$

Type of $\mathcal{P}_1$	Type of $\mathcal{P}_1$	Type of the line Δ	Type of $\mathcal{P}_2$	Type of $\mathcal{P}_2$
Base circle	Space-like	Space-like	Time-light	Poncelet
		Time-light	Space-like	Base circle
		Light-like	Light-like	Tangent spheres
Poncelet	Time-light	Space-like	Space-like	Base circle
Tangent spheres	Light-like	Light-like	Space-like	Base circle
		Space-like	Light-like	Tangent spheres

$$\vec{\Pi}_0(0)\blacksquare\,\vec{\Pi}_0\left(\frac{\pi}{2}\right)=0$$

permits to simplify the representation of the pencil $\mathcal{P}_t$ as follows

$$\vec{\Pi}_0(t)=\cos(t)\vec{\Pi}_0(0)+\sin(t)\vec{\Pi}_0\left(\frac{\pi}{2}\right)$$

and the type of the 2-plane $\mathcal{P}_1$ containing the point $\Pi_0(t)$ is space-like. Then, the second pencil is defined by a 2-plane $\mathcal{P}_2$ passing through O_4 and perpendicular to the plane $\mathcal{P}_1$. Immediately, one can note

$$\vec{\Pi}_0(0)\blacksquare\,\overrightarrow{e_\infty}=\vec{\Pi}_0\left(\frac{\pi}{2}\right)\blacksquare\,\overrightarrow{e_\infty}=0$$

The representation of the point Ω_0 is $\overrightarrow{o_0}$ (1,1,1,1) and a similar result

$$\vec{\Pi}_0(0)\blacksquare\,\overrightarrow{o_0}=\vec{\Pi}_0\left(\frac{\pi}{2}\right)\blacksquare\,\overrightarrow{o_0}=0$$

is obtained. So, the plane $\mathcal{P}_2$ is a time-like plane defined by O_4, $\overrightarrow{o_0}$, and $\overrightarrow{e_\infty}$. The second pencil is defined by

$$\left(u\overrightarrow{o_0}+v\overrightarrow{e_\infty}\right)^2=1$$

which leads to

$$2uv\overrightarrow{o_0}\blacksquare\,\overrightarrow{e_\infty}=1$$

The computation $\overrightarrow{o_0}\blacksquare\,\overrightarrow{e_\infty}=-1$ leads to

$$v=-\frac{1}{2u}$$

and the representation of the second pencil is

$$\begin{aligned}\vec{\sigma}(t)&=u\overrightarrow{o_0}-\frac{1}{2u}\overrightarrow{e_\infty}\\&=u\overrightarrow{e_o}+u\overrightarrow{e_1}+u\overrightarrow{e_2}+\frac{2u^2-1}{2u}\overrightarrow{e_\infty}\end{aligned}$$

which leads to a pencil of concentric circles of center Ω_0, and of radius $r_u=\frac{1}{u}$. In fact, this pencil is a Poncelet pencil with a limit point at the infinity, see Fig. 7.

The reader can note that if the first pencil is a pencil of parallel lines $\mathcal{L}_{1,i}$, the second pencil is a pencil of parallel lines $\mathcal{L}_{2,j}$ and for any i and j, the lines $\mathcal{L}_{1,i}$ and $\mathcal{L}_{2,j}$ are perpendicular.

Example with a Pencil of Circles Which Base Points in ε_2

Let $\mathcal{P}_t$ be the pencil of circles with base points M_1 (0, 3) and M_2 (0, −1). Let Ω_0 (1; 1) be the midpoint of the segment $[M_1\ M_2]$. Let $\overrightarrow{\sigma_0}\left(\frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{-1}{2}\right)$ (resp. $\overrightarrow{\pi_0}(0,1,0,1)$) be the representation in the Minkowski-Lorentz space $\mathrm{L}_{3,1}$ of the circle of diameter $[M_1\ M_2]$ (resp. the line defined by the point Ω_0 and the normal vector $\frac{1}{M_1M_2}\overrightarrow{M_1M_2}$). The representation of the pencil $\mathcal{P}_t$ in $\mathrm{L}_{3,1}$ is

$$\vec{\sigma}(t)=\cos(t)\overrightarrow{\sigma_0}+\sin(t)\overrightarrow{\pi_0}$$

The representations of M_1 and M_2 in $\mathrm{L}_{3,1}$ are

$$\begin{cases}\overrightarrow{m_1}(1,1,3,5)\\ \overrightarrow{m_2}(1,1,-1,1)\end{cases}$$

with

$$\overrightarrow{m_1}\blacksquare\,\overrightarrow{\sigma_0}=\overrightarrow{m_1}\blacksquare\,\overrightarrow{\pi_0}=\overrightarrow{m_2}\blacksquare\,\overrightarrow{\sigma_0}=\overrightarrow{m_2}\blacksquare\,\overrightarrow{\pi_0}=0$$

The second pencil is defined by

$$\left(u\overrightarrow{m_1}+v\overrightarrow{m_2}\right)^2=1$$

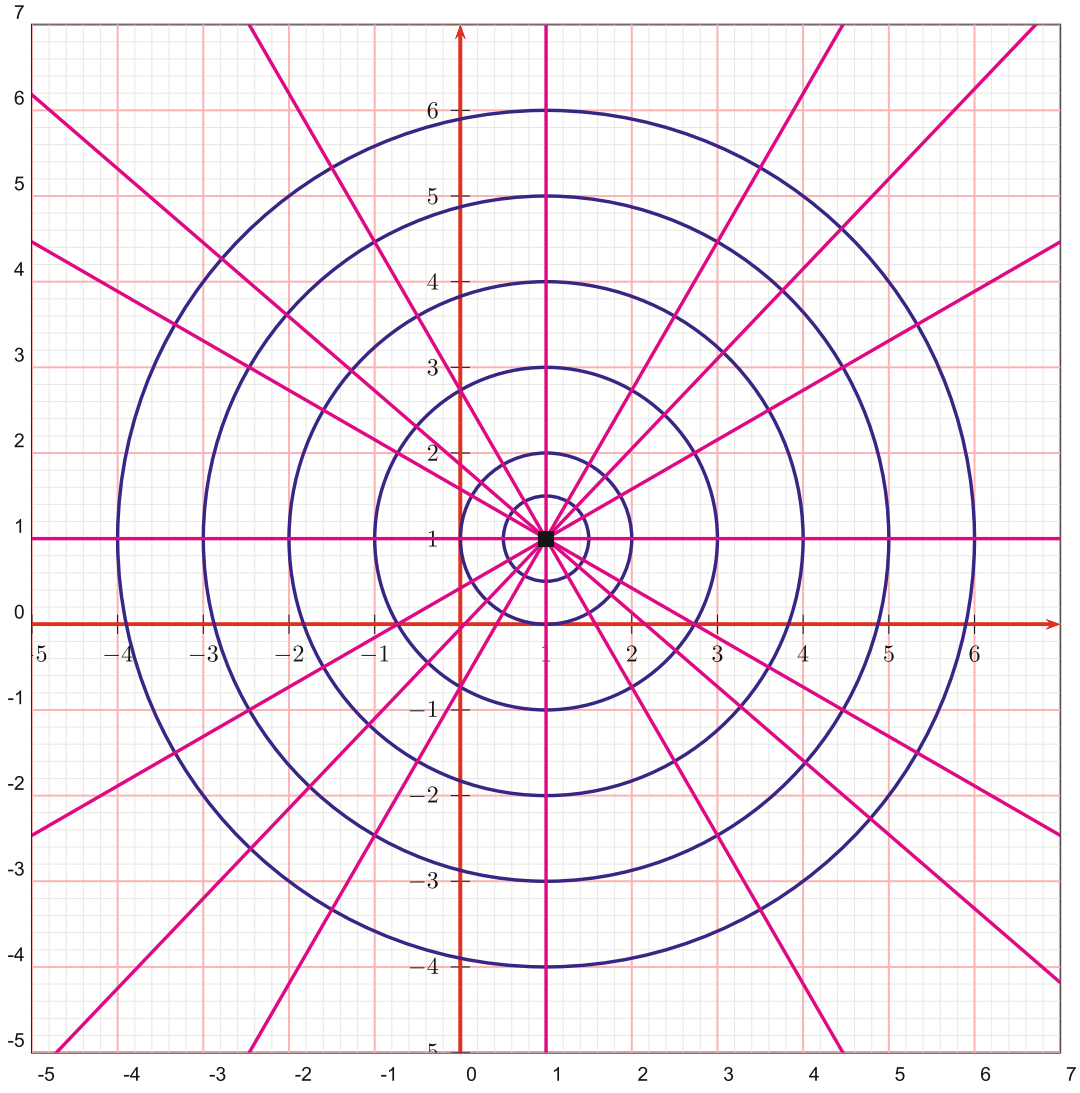
which leads to

$$2uv\overrightarrow{m_1}\ \ \overrightarrow{m_2}=1$$

As $\overrightarrow{m_1}\blacksquare\,\overrightarrow{m_2}=-8$, the relation

$$v=-\frac{1}{16u}$$

is obtained and the representation of the second pencil is



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 7 Two pencils of orthogonal circles. The lines are obtained with $t \in \left\{0, \frac{\pi}{6}, \frac{\pi}{4}, \frac{\pi}{3}, \frac{\pi}{2}, \frac{2\pi}{3}, \frac{3\pi}{4}, \frac{5\pi}{6}\right\}$ whereas the circles with the center Ω_0 are obtained with $u \in \left\{2, 1, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{1}{5}\right\}$

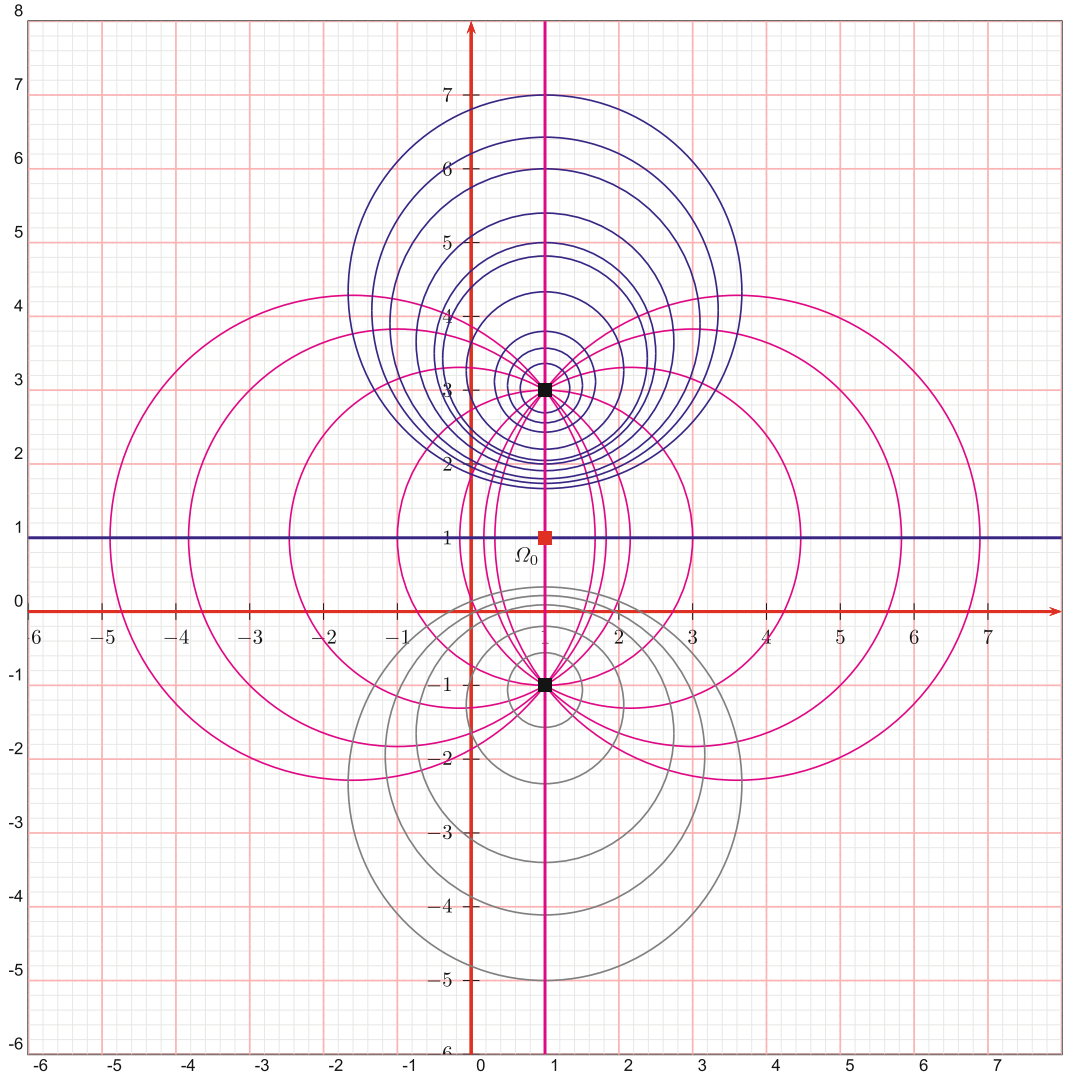
$$\begin{aligned}\vec{\sigma}\,(t) &= u\,\overrightarrow{m_1} - \frac{1}{16\,u}\,\overrightarrow{m_2} \\ &= \frac{16\cdot u^2-1}{16\cdot u}\,\overrightarrow{e_o} + \frac{16\cdot u^2-1}{16\cdot u}\,\overrightarrow{e_1} \\ &\quad + \frac{48\cdot u^2+1}{16\cdot u}\,\overrightarrow{e_2} + \frac{80\cdot u^2-1}{16\cdot u}\,\overrightarrow{e_\infty}\end{aligned}$$

which leads to a pencil of concentric circles of center $\Omega_u\left(1, \frac{48\,u^2+1}{16\,u^2-1}\right)$ and of radius $r_u = \frac{16\,u}{16\,u^2-1}$ where $u \in \mathbb{R} - \left\{-\frac{1}{4}, \frac{1}{4}\right\}$, see Fig. 8.

If $u = \frac{\varepsilon}{4}$ with $\varepsilon \in \{-1, 1\}$, $\vec{\sigma}\left(\frac{\varepsilon}{4}\right)$ is computed as follow

$$\begin{aligned}\vec{\sigma}\left(\frac{\varepsilon}{4}\right) &= \frac{\varepsilon}{4}\,\overrightarrow{m_1} - \frac{\varepsilon}{4}\,\overrightarrow{m_2} = \frac{\varepsilon}{4}\left(\overrightarrow{m_1} - \overrightarrow{m_2}\right) \\ &= \varepsilon\,\overrightarrow{e_2} + \varepsilon\,\overrightarrow{e_\infty}\end{aligned}$$

which represents the line defined by the point Ω_0 and the normal vector $\overrightarrow{e_2}$, see the blue line in Fig. 8.



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 8 Two pencils of orthogonal circles. The circles of the pencil $\mathcal{P}_t$ are obtained with $|\ t\ | \in \left\{0, \frac{\pi}{6}, \frac{\pi}{4}, \frac{7\pi}{24}, \frac{\pi}{2}\right\}$. The blue circles of the Poncelet pencil are obtained with $u \in \left\{\frac{1}{2}, \frac{7}{12}, \frac{13}{24}, \frac{2}{3}, \frac{3}{4}, \frac{4}{5}, 1, \frac{3}{2}, 2, 3\right\}$ whereas the gray circles of the Poncelet pencil are obtained with $u \in \left\{\frac{1}{32}, \frac{1}{16}, \frac{3}{32}, \frac{7}{64}, \frac{1}{8}\right\}$

One can note that the base points M_1 and M_2, in black in Fig. 8, of the first pencil $\mathcal{P}_t$ are the limit points of the Poncelet pencil.

Example with a Pencil of Tangent Circles in $\mathcal{E}_2$

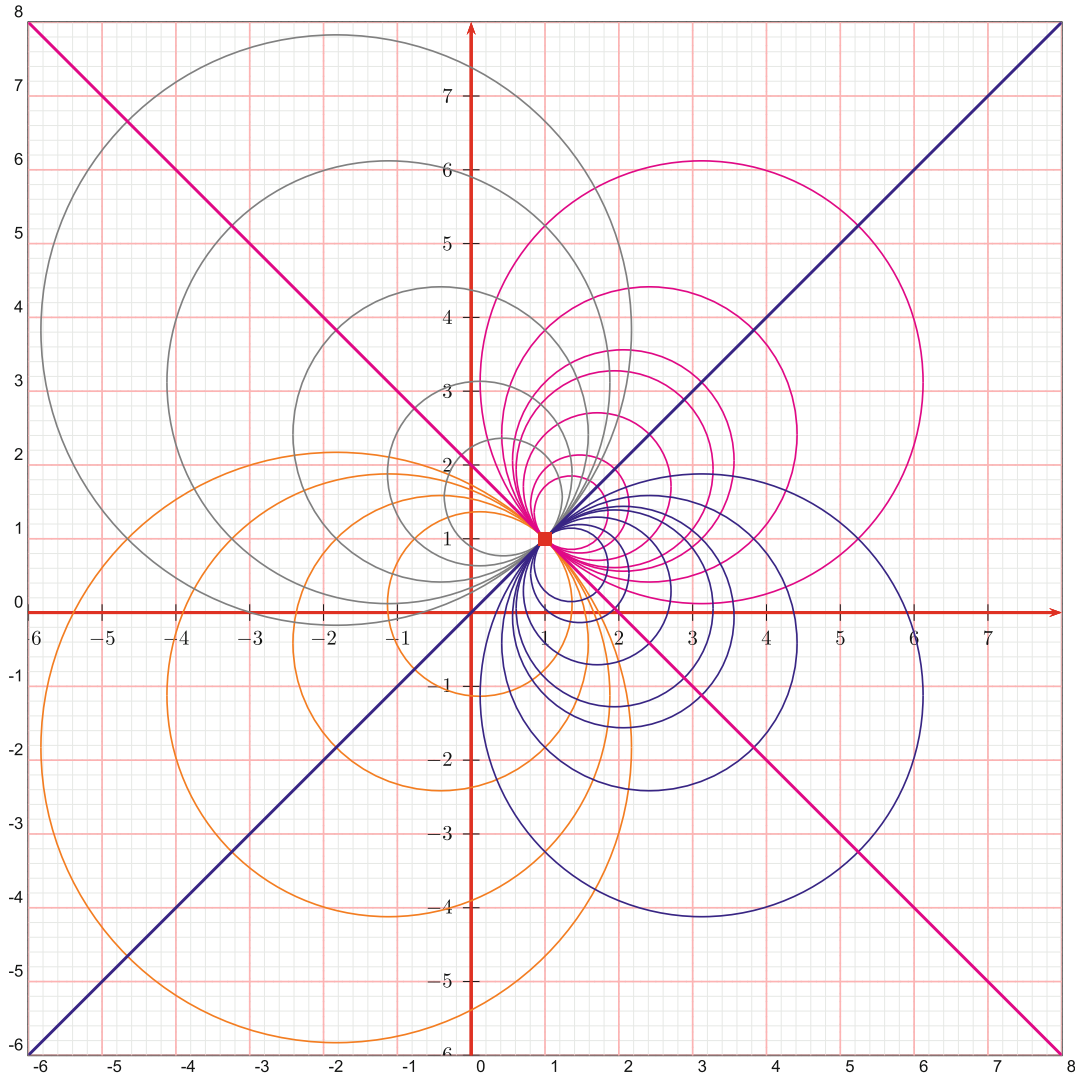
Let $\mathcal{P}_t$ be the pencil of circles tangent at the points $\Omega_0\ (1,\ 1)$ and centered on the line defined by Ω_0 and $\vec{u}\,(1,1)$. The representation of the line generated by Ω_0 and $\overrightarrow{u_0}\left(\frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}\right)$ in $\mathrm{L}_{3,1}$ is

$$\overrightarrow{\pi_0}\left(0, \frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}, \sqrt{2}\right)$$

and the pencil is represented by

$$\overrightarrow{\sigma_0}\,(t) = \overrightarrow{\pi_0} + t\,\overrightarrow{o_0}$$

where $\overrightarrow{o_0}\,(1,1,1,1)$ is the representation of the point Ω_0. The center (resp. radius) of the circle of the pencil is $\Omega_0(t)\left(\frac{2t+\sqrt{2}}{2t}, \frac{2t+\sqrt{2}}{2t}\right)$ (resp. $\rho_0(t) = \frac{1}{t}$).



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 9 Two pencils of orthogonal circles. The magenta (resp. orange) circles of the pencil $\mathcal{P}_t$ are obtained with $t \in \left\{\frac{1}{3}, \frac{1}{2}, \frac{2}{3}, \frac{3}{4}, 1, \frac{3}{2}, 2\right\}$ (resp. $t \in \left\{-\frac{1}{4}, -\frac{1}{3}, -\frac{1}{2}, -\frac{4}{5}\right\}$). The blue (resp. gray) circles of the second pencil are obtained with $u \in \left\{\frac{1}{3}, \frac{1}{2}, \frac{2}{3}, \frac{3}{4}, 1, \frac{3}{2}, 2\right\}$ (resp. $u \in \left\{-\frac{1}{4}, -\frac{1}{3}, -\frac{1}{2}, -\frac{4}{5} - \frac{5}{4}\right\}$)

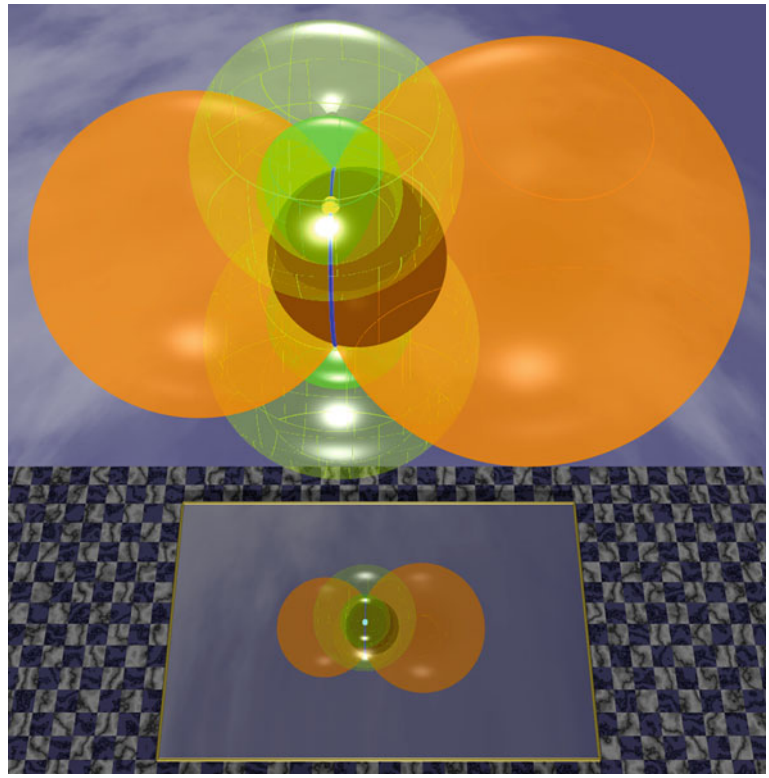
The pencil $\mathcal{P}_t$ is represented by the 2-plane defined by the point O_4, the space-like vector $\overrightarrow{\pi_0}$ and the light-like vector $\overrightarrow{o_0}$ which is orthogonal to itself. The second pencil is defined by a light-like 2-plane generated by the point O_4, a space-like vector $\overrightarrow{\pi_1}$ and the light-like vector $\overrightarrow{o_0}$. To simplify the computation, the space-like vector $\overrightarrow{\pi_1}(0, x_1, x_2, x_\infty)$ represents a plane and verifies the following conditions:

$$\begin{cases} \overrightarrow{\pi_0} \blacksquare \overrightarrow{\pi_1} &= \frac{\sqrt{2}}{2}x_1 + \frac{\sqrt{2}}{2}x_2 &= 0 \\ \overrightarrow{o_0} \blacksquare \overrightarrow{\pi_1} &= x_1 + x_2 - x_\infty &= 0 \\ \overrightarrow{\pi_1}^2 &= x_1^2 + x_2^2 &= 1 \end{cases}$$

and one solution is

$$\overrightarrow{\pi_1}\left(0, \frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}, 0\right)$$

P



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 10 Two pencils of orthogonal spheres. The color of the spheres of the pencil $\mathcal{P}_t$ is orange and the color of the circle is blue. The color of the spheres of the Poncelet pencil is green, and the colors of the limit point are yellow and cyan

which is the representation of the line defined by the point Ω_0 and the normal vector $\overrightarrow{u_1}\left(\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}\right)$. One can note that the second solution is $-\overrightarrow{\pi_1}$. So, the pencil is represented by

$$\overrightarrow{\sigma_1}(u) = \overrightarrow{\pi_1} + u\,\overrightarrow{o_0}$$

and the center (resp. radius) of the circle of the pencil is $\Omega_1(u)\left(\frac{2u+\sqrt{2}}{2u}, \frac{2u-\sqrt{2}}{2u}\right)$ (resp. $\rho_1(u) = \frac{1}{u}$), see Fig. 9.

One can note that

$$\begin{aligned}\overrightarrow{\sigma_0}(t)_{\blacksquare}\,\overrightarrow{\sigma_1}(u) &= \left(\overrightarrow{\pi_0} + t\,\overrightarrow{o_0}\right)_{\blacksquare}\left(\overrightarrow{\pi_1} + u\,\overrightarrow{o_0}\right)\\ &= \underbrace{\overrightarrow{\pi_0}_{\blacksquare}\,\overrightarrow{\pi_1}}_{0} + u\underbrace{\overrightarrow{\pi_0}_{\blacksquare}\,\overrightarrow{o_0}}_{0} + t\underbrace{\overrightarrow{o_0}_{\blacksquare}\,\overrightarrow{\pi_1}}_{0}\\ &\quad + \underbrace{\overrightarrow{o_0}^2}_{0}\\ &= 0\end{aligned}$$

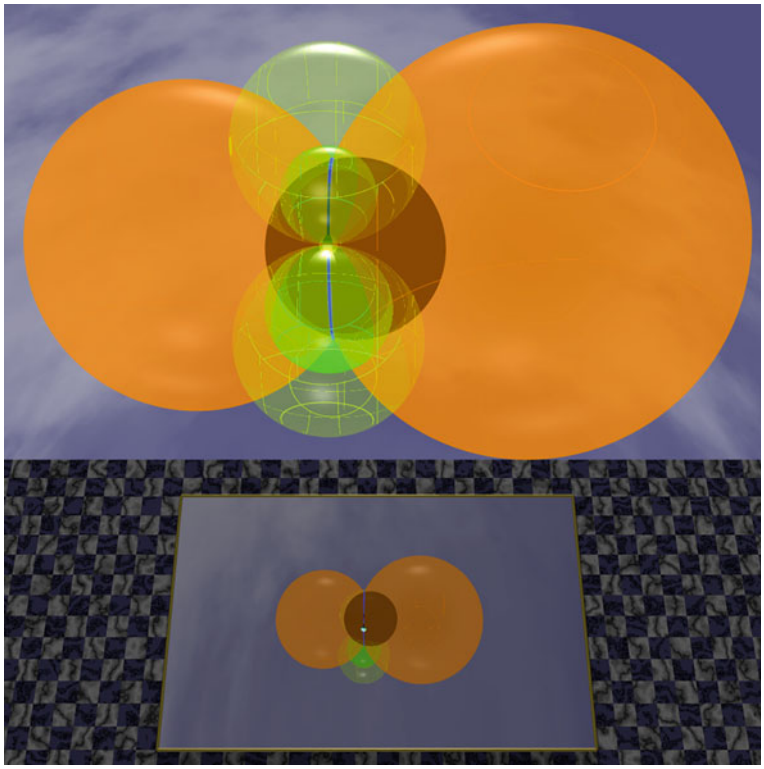
Moreover, the dimension of the vector space generated by $\overrightarrow{\pi_0}$, $\overrightarrow{\pi_1}$ and $\overrightarrow{o_0}$ is $3 < 4$. A light-like direction misses. The vector $\overrightarrow{e_\infty}$ is orthogonal to the representation of any lines of $\mathcal{E}_2$, so, a basis of $\overrightarrow{L_{3,1}}$ is $\left(\overrightarrow{\pi_0}, \overrightarrow{\pi_1}, \overrightarrow{o_0}, \overrightarrow{e_\infty}\right)$.

Example with a Pencil of Spheres which Base Circle in $\mathcal{E}_3$

In this section, let $\mathcal{P}_t$ be the pencil of spheres obtained by the transformation of circles in section "Example with a Pencil of Circles Which Base Points in ε_2" into spheres having the same radii. Using the type of the line, Table 5, one can choose the kind of the second pencil.

Poncelet Pencil with Spheres Orthogonal to the Spheres of $\mathcal{P}_t$

Using the space-like line Δ defined by the point O_3 and the vector $\overrightarrow{e_3}$, the circles of the second pencil in section "Example with a Pencil of Circles Which Base Points in ε_2" are transformed into spheres having the same radii, see Fig. 10.



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 11 Two pencils of orthogonal spheres. The color of the spheres of the pencil $\mathcal{P}_t$ is orange and the color of the circle is blue. The color of the spheres of the pencil of the tangent spheres is green. The color of the point of tangency is yellow whereas the color of the point which generates the fifth dimension is cyan (see the mirror)

Pencil of Tangent Spheres Orthogonal to the Spheres of $\mathcal{P}_t$

To obtain a light-like 2-plane, the type of the line Δ is light-like defined by the light-like vector

$$\vec{\nabla}(1, x_1, x_2, x_3, x_\infty)$$

which verifies

$$\begin{cases} \vec{\sigma_0} \blacksquare \vec{\nabla} = 0 \\ \vec{\pi_0} \blacksquare \vec{\nabla} = 0 \\ \vec{\nabla}^2 = 0 \end{cases} \tag{29}$$

with $\vec{\sigma_0}\left(\frac{1}{2}, \frac{1}{2}, \frac{1}{2}, 0, \frac{-1}{2}\right)$ (resp. $\vec{\pi_0}(0, 1, 0, 0, 1)$). Let x_3 be the degree of freedom. The system of Formula (29) is equivalent to

$$\begin{cases} x_1 + x_2 - x_\infty + 1 = 0 \\ x_1 - 1 = 0 \\ x_1^2 + x_2^2 + x_3^2 - 2x_\infty = 0 \end{cases} \tag{30}$$

which leads to

$$\begin{cases} x_2 = x_\infty - 2 \\ x_1 = 1 \\ x_\infty^2 - 6x_\infty + 5 + x_3^2 = 0 \end{cases} \tag{31}$$

The third equation have real solutions if

$$16 - 4x_3^2 \geq 0$$

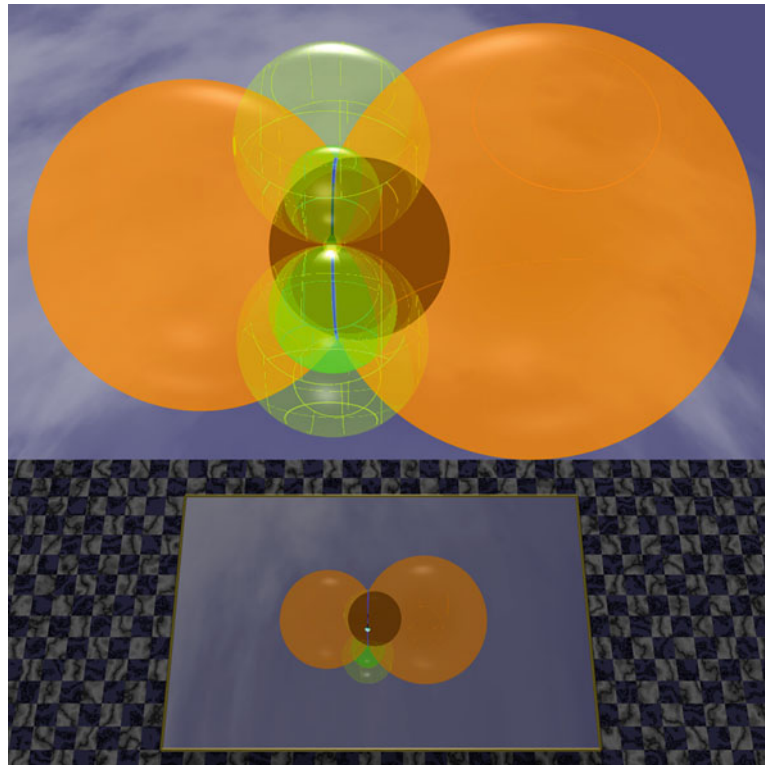
which is equivalent to

$$| x_3 | < 2$$

and the light-like vector is

$$\vec{\nabla_\varepsilon}\left(1, 1, 1 + \varepsilon\sqrt{4 - x_3^2}, x_3, 3 + \varepsilon\sqrt{4 - x_3^2}\right)$$

with $\varepsilon \in \{-1; 1\}$ which represents the point $M_l\left(1, 1 + \varepsilon\sqrt{4 - x_3^2}, x_3\right)$. If $\vec{\nabla_{-\varepsilon}}$ is the direction



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 12 Two pencils of orthogonal spheres. The color of the spheres of the pencil $\mathcal{P}_t$ is orange and the color of the circle is blue. The color of the spheres of the pencil of the tangent spheres is green. The color of the point of tangency is yellow whereas the color of the point which generates the fifth dimension is cyan (see the mirror)

of the line Δ, then $\overrightarrow{\nabla_\varepsilon}$ represents the point of tangency of the second pencil. The 2-plane $\overrightarrow{\pi_1}$ representing the second pencil verifies

$$\begin{cases} \overrightarrow{\sigma_0} \blacksquare \overrightarrow{\pi_1} = 0 \\ \overrightarrow{\pi_0} \blacksquare \overrightarrow{\pi_1} = 0 \\ \overrightarrow{\nabla_1} \blacksquare \overrightarrow{\pi_1} = 0 \\ \overrightarrow{\pi_1}^2 = 1 \end{cases} \tag{32}$$

which leads to

$$\overrightarrow{\pi_1}\left(0, 0, \frac{x_3}{2}, -\frac{\sqrt{4 - {x_3}^2}}{2}, \frac{x_3}{2}\right)$$

and the plane $\overrightarrow{\pi_1}$ represents the plane of $\mathcal{E}_3$ defined by the point Ω_0 and the normal vector $\overrightarrow{v_1}\left(0, \frac{x_3}{2}, -\frac{\sqrt{4-x_3^2}}{2}\right)$. Figure 11 shows an example with $x_3 = -1$.

Pencil of Spheres with Base Circle Orthogonal to the Spheres of $\mathcal{P}_t$

To obtain a space-like 2-plane, the type of the line Δ is time-like defined by the light-like vector

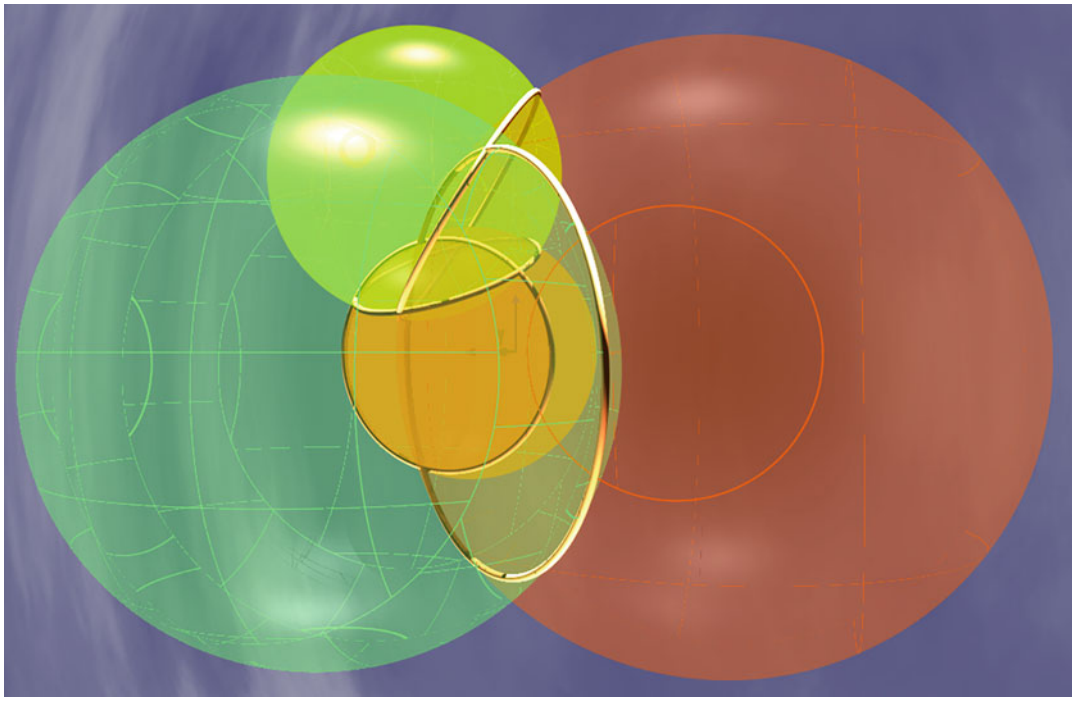
$$\vec{\nabla}\,(x_o, x_1, x_2, x_3, x_\infty)$$

which verifies

$$\begin{cases} \overrightarrow{\sigma_0} \blacksquare \vec{\nabla} = 0 \\ \overrightarrow{\pi_0} \blacksquare \vec{\nabla} = 0 \\ \vec{\nabla}^2 < 0 \end{cases} \tag{33}$$

with $\overrightarrow{\sigma_0}\left(\frac{1}{2}, \frac{1}{2}, \frac{1}{2}, 0, \frac{1}{2}\right)$ (resp. $\overrightarrow{\pi_0}\,(0, 1, 0, 0, 1)$). The system of Formula (29) is equivalent to

$$\begin{cases} x_o + x_1 + x_2 = x_\infty = 0 \\ x_1 - 1 = 0 \\ x_1^2 + x_2^2 + x_3^2 - 2x_o x_\infty = 0 \end{cases} \tag{34}$$



Pencils of Spheres in the Minkowski-Lorentz Spaces, Fig. 13 Two spheres of each pencil of orthogonal spheres, Fig. 12 and the circles of intersection

which leads to

$$\begin{cases} x_\infty = 2x_o + x_2 \\ x_1 = x_o \\ x_2^2 + x_3^2 - 3x_o^2 - 2x_o x_2 < 0 \end{cases} \tag{35}$$

$x_o = x_1 = 1$, $x_2 = 2$, and $x_3 = 1$ which lead to $x_\infty = 4$ and $\overrightarrow{\nabla}^2 = -2$. To simplify the computations, the 2-plane representing the second pencil is generated by $\overrightarrow{\pi_1}\,(0, y_1, y_2, y_3, y_\infty)$ (resp. $\overrightarrow{\sigma_1}\,(z_o, z_1, z_2, z_3, z_\infty)$) which represents a plane (resp. sphere) of $\mathcal{E}_3$. The vector $\overrightarrow{\pi_1}$ verifies

$$\begin{cases} \overrightarrow{\sigma_0} \blacksquare \overrightarrow{\pi_1} = 0 \\ \overrightarrow{\pi_0} \blacksquare \overrightarrow{\pi_1} = 0 \\ \overrightarrow{\nabla_1} \blacksquare \overrightarrow{\pi_1} = 0 \\ \overrightarrow{\pi_1}^2 = 1 \end{cases} \tag{36}$$

which leads to

$$\overrightarrow{\pi_1}\left(0, 0, \frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}\right)$$

or $-\overrightarrow{\pi_1}$. The plane $\overrightarrow{\pi_1}$ represents the plane of $\mathcal{E}_3$ defined by the point Ω_0 and the normal vector $\overrightarrow{v_1}\left(0, \frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}\right)$. The vector $\overrightarrow{\sigma_1}$ verifies

$$\begin{cases} \overrightarrow{\sigma_0} \blacksquare \overrightarrow{\sigma_1} = 0 \\ \overrightarrow{\pi_0} \blacksquare \overrightarrow{\sigma_1} = 0 \\ \overrightarrow{\pi_1} \blacksquare \overrightarrow{\sigma_1} = 0 \\ \overrightarrow{\nabla_1} \blacksquare \overrightarrow{\sigma_1} = 0 \\ \overrightarrow{\sigma_1}^2 = 1 \end{cases} \tag{37}$$

which leads to

$$\overrightarrow{\sigma_1}\left(\frac{1}{2}, \frac{1}{2}, \frac{3}{2}, 1, \frac{5}{2}\right)$$

or $-\overrightarrow{\sigma_1}$. The vector $\overrightarrow{\sigma_1}$ represents the sphere of $\mathcal{E}_3$ of center Ω_1 (1, 3, 2) and of radius $\rho_1 = 2$. The representation of the second pencil in $L_{4,1}$ is

P

$$\vec{\tau}(t) = \cos(t)\vec{\sigma_1} + \sin(t)\vec{\pi_1}$$

Figure 12 shows some spheres of these pencils.

Figure 13 shows two spheres of these pencils and the circles.

Conclusion

This entry presents an application of the Minkowski-Lorentz space and its interest for Computer Graphics: the representation and computations of pencils of circles or spheres. These pencils are represented by unit circles, that is, the intersection between the unit hypersphere Λ^{n+1} and a 2-plane passing through the origin. From a Euclidean point of view, these unit circles look like ellipse, hyperbola, or the union of two straight lines. So, these pencils can be represented using rational quadratic Bézier curves and mass points. Moreover, from a pencil of spheres, this kind of representation eases the computation of an other pencil of orthogonal spheres (a sphere of a pencil is orthogonal to the spheres of the other pencil): the construction of a 2-plane passing through the origin and orthogonal to the previous 2-plane leads to the second pencil.

In the future, from a pencil of spheres in the 3D usual Euclidean space, a one-parameter family of Dupin cyclides will be computed using the Minkowski-Lorentz space.

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Perception AI

► Character Artificial Intelligence

Perceptual Illusions and Distortions in Virtual Reality

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Synonyms

Distance misperception; Self-motion misperception; Vection; Virtual body-ownership

Definitions

Virtual Reality (VR) enables users to act and perceive as they do during everyday interactions with the word. As a consequence, VR may deliberately or inadvertently elicit a range of perceptual illusions and distortions on behalf of immersed users.

Introduction

From an early age, people become experts at deciphering the continuous stream of stimuli registered by various sensory systems in response to the perceiver's own actions and events in the environment. However, even though the senses provide reasonably reliable information, perception is imperfect, leaving the perceiver vulnerable to illusions, i.e., instances of erroneous or misinterpreted perceptions of sensory information (Stevenson 2010).

A defining feature of Virtual Reality (VR) systems is that they support natural perception and actions by means of high fidelity tracking and displays. That is, VR systems support a sensorimotor loop similar to that of the real world and enable users to interact and perceive as they would during unmediated experiences. Thus, VR systems may inadvertently or deliberately elicit a range of perceptual illusions and distortions. Based on our previous writings on the topic (Serafin et al. 2014), this entry details a selection of well-documented perceptual illusions and distortions known to occur during exposure to VR and discusses how they can be leveraged in order to provide more compelling experiences of virtual environments (VEs).

Illusions of Place and Plausibility

What separates VR from traditional audiovisual media is arguably that it elicits an unprecedented degree of presence on behalf of the user. A number of different conflicting and complimentary theories of presence have been proposed (e.g., Lombard and Ditton 1997; Riva et al. 2011; Waterworth and Waterworth 2001). However, the view of presence advocated by Slater and colleagues is particularly relevant to the current discussion because it explicitly focuses on presence as a response to VR (e.g., Sanchez-Vives and Slater 2005; Slater 2009; Slater et al. 2010a). Generally, the degree of presence is viewed as the extent to which the user responds to realistically to the VE. If the VE elicits a high degree of presence then users will respond more or less exactly as they would when exposed to an equivalent scenario in the real world. This implies that the presence response occurs on multiple levels ranging from unconscious and automatic physiological and behavioral responses to higher level processes involving deliberation and thoughts. Thus, even though presence is subjectively felt, the presence response cannot be reduced to a subjective experience (Sanchez-Vives and Slater 2005). Nevertheless, Slater et al. (2010a) have argued that the presence response happens as a function of two illusions: the *place illusion* (PI) and the *plausibility illusion* (Psi).

PI can be described as to the illusion of "being there" in the VE. This illusion occurs in response to the VR system supporting the normal sensorimotor contingencies of the user (i.e., the normal actions the user can perform in order to perceive and affect the VE). For example, if the user turns her head or kneels down then displayed image and sound should reflect this change in perspective, and if she reaches out and grasps an object then this action should cause that object to move (Slater 2009). Specifically, Slater et al. (2010a) describe that when "a person perceives by carrying out actions that result in changes in (multisensory) perception much as in physical reality, then the simplest hypothesis for the brain to adopt is that what is being perceived is actually there" (p. 3). The concept technological *immersion* is sometimes associated with systems that support normal sensorimotor contingencies. That is, the degree of immersion is defined as the range of normal sensorimotor contingencies supported by the system.

Psi, the second illusion introduced by Slater (2009), refers to the illusion that the events happening virtually are indeed happening. Rovira et al. (2009) argue that Psi is a more difficult illusion to elicit than PI, and it requires that the VE satisfies at least three criteria: (1) The VE should be *correlational*. The user's actions produce correlated reactions within the VE (e.g., a virtual character might avoid eye-contact and step aside if the user stares and exhibit aggressive body language). (2) The VE should be *self-referential*. The VE responds directly to the

user's presence even when the user does not perform an instigating action (e.g., a virtual character might react to the presence of the user without the user initially approaching or addressing said character). (3) The VE should be *credible*. The VE conform to the user's knowledge and expectations accrued through a lifetime of nonmediated interactions. Notably, Skarbez et al. (2017) have introduced the concept *coherence* as a (possibly) objective characteristic of the VE that gives rise to Psi. Importantly, coherence is viewed as a superset of realism, implying that in order to be coherent the VE need not strictly adhere to real-world laws and norms. Instead, coherence depends on the degree to which the user finds the virtual experience to possess internal logic and behavioral consistency. Thus, a virtual fantasy world may be coherent as long as fantastic events and behaviors are consistent.

Finally, Slater (2009) has described the virtual body as "a focal point where PI and Psi are fused" (p. 3554). The virtual body will be the topic of the following section.

Body Ownership Illusions

Individuals make sense of incoming sensory stimuli based on tacit expectations as to how these stimuli relate to their own actions and events in the environment. Thus, when reaching for an object, you expect to see your extended arm, and when directing your gaze downward, you expect to see your own body. However, when immersed in a VE, you cannot take for granted that such actions will bring your body into view. If the user is wearing a head-mount display (HMD), her real body will be occluded and tracking of the various body-parts is necessary in order to map a virtual representation onto the real body. When done successfully this may cause the user to experience an illusion of virtual body ownership, i.e., the experience that an artificial body is in fact one's own physical body (Maselli and Slater 2013).

The illusion of ownership of artificial body-parts was first demonstrated without the use of VR technology. Specifically, Botvinick and Cohen (1998) documented the so-called *rubber hand illusion* where subjects experienced a sense of ownership over a rubber hand placed in front of them when tactile stimuli was synchronously applied to their real hand and the rubber hand. Ten years after the rubber hand illusion was first described, Slater et al. (2008) showed that it can be replicated in VR. Work by Maselli and Slater (2013) explored the perceptual underpinnings for full body ownership illusions in VR. Their work among other things revealed that (1) a first person perspective is central to the virtual body-ownership. (2) Visio-proprioceptive cues can elicit body-ownership illusions when users are exposed to a virtual body that spatially overlaps with the real body from a first person perspective. (3) When the spatial overlap or the realism of virtual body is limited, then multisensory or sensorimotor cues are necessary in order to produce the body-ownership illusion.

Interestingly, virtual body-ownership illusions can occur even when the virtual body differs from the users own body. For example, the illusion can occur when the virtual and real bodies differ in regard to size (Normand et al. 2011), gender (Slater et al. 2010b), age (Banakou et al. 2013), and race (Maister et al. 2013). Moreover, ownership illusions may even occur when the subject is exposed to nonhuman virtual bodies (e.g., humanoid robots and cartoon-like avatars Lugrin et al. 2015) and when these bodies have additional limbs (e.g., a virtual tail Steptoe et al. 2013). Work exploring the effects on virtual body-ownership suggests that ownership of a foreign body affects subject' perceptions, attitudes, and actions. For example, implicit racial bias may be reduced when subjects have been exposed to a virtual body with a different skin color (Peck et al. 2013) and adult subjects embodying a child's body may be more likely to overestimate the size of virtual objects (Banakou et al. 2013).

Distortions of Virtual Distances

Perceptual distortions of virtual spaces and objects are not only phenomena that occur when

users embody a foreign avatar, such as an adult inhabiting the virtual body of a child. One of the most well-documented perceptual distortions of virtual spaces relate to the perception of egocentric distances. Users tend to underestimate virtual distances. That is, individuals tend to find the distance between their own position and virtual objects shorter than it really is. Based on a review of the literature, Renner et al. (2013) broadly divide the factors influencing virtual distance misperception into four categories: technical factors, compositional factors, human factors, and measurement methods.

Technical factors do as the name implies relate to the properties of the software and hardware used to render and display the VE. Specifically, Renner et al. (2013) highlight a number of properties of HMDs that may account for some of the underestimation. For example, some of the underestimation may be attributed to the combination of a restricted field of view (FOV), the mass and moment of inertia of HMDs, along with the feeling of wearing the HMDs. Moreover, the accommodation-convergence conflict may introduce underestimations, but it is unclear whether graphics quality is of influence.

Compositional factors relate to the features of the VE presented to the user. The review by Renner et al. (2013) suggests that the literature is fairly consistent in regard to the effects of pictorial depth cues on distance perception. Particularly, the authors describe that distance estimates may be positively influenced by the addition of complexity to the VE. Moreover, the use of a correct avatar may also improve distance estimates.

The third category, *human factors*, relate to the users' psychological characteristics. Renner et al. (2013) describe that distance estimation does not appear to be influenced by gender or variations in age among adults. The ability to estimate virtual distances may be improved by providing individuals with feedback on their performance. However, the resulting adaptation to virtual distances may necessarily reduce transfer of skills from VR to real life.

In regard to the final group of factors, *measurement methods*, a number of different measures have been proposed. All measures quite consistently suggest that individuals underestimate egocentric distances in VR. However, different measures are a likely to produce difference estimates of the underestimation. Renner et al. (2013) describe that blind throwing and blind walking estimates yield comparable results; blind reaching estimates may offer higher accuracy and consistency than verbal estimates; timed imagined walking and blind walking produce similar estimates; and blind walking estimates are generally more accurate than estimates resulting from triangulated blind walking and indirect blind walking.

Finally, Renner et al. (2013) recommend that in order to facilitate the best possible distance estimation in VEs, developers should "provide binocular disparity, use high quality of graphics, carefully adjust the virtual camera settings, display a rich virtual environment containing a regularly structured ground texture, and enhance the user's sense of presence" (p. 23).

Self-motion Illusions and Distortions

It is not just the perception of virtual distances that are prone to misperceptions. Virtual walking accomplished using a treadmill may also be accompanied by perceptual distortions. If a user were walking on a linear treadmill while wearing a HMD, then one would expect that the visual speed presented to the user should match the speed of the treadmill's belt. However, it has been demonstrated that the walker is likely to perceive matched visual speeds as too slow (Banton et al. 2005; Kassler et al. 2010; Nilsson et al. 2016; Powell et al. 2011). Notably, a similar perceptual distortion appears to be present when users are relying on walking-in-place techniques for virtual travel (Nilsson et al. 2016). While the phenomenon and its causes have yet to be fully understood, previous user studies have yielded the following insights: (1) The distortion may be eliminated if walkers direct their gaze downwards or to the side (Banton et al. 2005). (2) Image jitter does not appear to be responsible for the distortion (Banton et al. 2005). (3) No effect of increased

HMD weight or varying peripheral occlusion have been found (Nilsson et al. 2015a, b). (4) The degree of underestimation appears to be inversely proportional to the size of the display FOV and the geometric FOV (Nilsson et al. 2014a; 2015a). (5) The degree of identified underestimation may vary depending on study methods (Nilsson et al. 2015a). (6) High step frequencies may lead to a larger degree of underestimation, but the evidence is somewhat equivocal with respect to this effect (Nilsson et al. 2014b; Durgin et al. 2007; Kassler et al. 2010); (7) Finally, the degree of underestimation may vary slightly depending on whether the user is walking on a treadmill or walking in place (Nilsson et al. 2016).

Turning to the topic of illusory self-motion, one does not need to be immersed in a VE in order to experience visually induced self-motion illusions, that is, *vection* (Lowther and Ware 1996). The following scenario is likely to elicit a vection illusion. A passenger is sitting on a stationary train, looking out the window at another train in the adjacent track. When this second departs, the passenger experiences a transient, yet compelling, that she is on board the trains which is moving. This example illustrates how optokinetic stimuli may be open to at least two perceptual interpretations (Brandt et al. 1973). The passenger either (falsely) perceives the surroundings as being stationary, while she is moving or (correctly) perceives herself as being stationary while the second train is moving. Riecke et al. (2005b) describe that vection is influenced both by the properties of the physical stimuli indicative of self-motion (*bottom-op factors*) and by the perceivers' expectations to and interpretation of said stimuli (*top-down factors*). Notably, visual stimuli is not a prerequisite for vection, as self-motion illusions can occur during exposed to auditory, vibrotactile, and biomechanical stimulation (Nordahl et al. 2012; Riecke et al. 2005a; Riecke and Schulte-Pelkum 2013; Väljamäe 2009). The bottom-up factors affecting visually induced self-motion illusions include the stimuli's speed of movement, the perceived depth structure of the visual stimuli, and the area of the visual field occupied by the stimuli (Riecke et al. 2005a). Three of the three primary auditory cues for discrimination of motion are sound intensity, binaural cues, and the Doppler effect (Väljamäe 2009). Recent work on haptically induced self-motion illusions used a combination of vibrotactile stimulation to the main supporting areas of the feet and a virtual elevator to elicit sensations of upward and downward movements (Nordahl et al. 2012). Because the walls of the virtual elevator were opaque, no visual self-motion cues were presented (i.e., optic flow). Thus, it seems likely that the participants' expectation of vertical movement (a top-down factor) contributed to the illusion. Other examples of top-down factors shown to affect vection include the belief that self-motion is possible (Riecke et al. 2005b, 2008; Wright et al. 2006), and explicitly being asked to attend to either the sensation of self-motion or object motion (Palmisano and Chan 2004).

Leveraging Perceptual Illusions in VR

A defining feature of VR is arguably its ability to elicit both the illusion of "being there" in the VE (the place illusion) and the illusion that the unfolding events are indeed happening (the plausibility illusion). As a consequence, the VR system may cause the user to respond realistically to the VE (a presence response). Bowman and McMahan (2007) have argued that it is precisely this ability to produce experiences greatly resembling "the real thing" that is responsible for the success of many past VR applications. For example, virtual exposure therapy functions because the VE can elicit a elicit a genuine fear response, and military and medical training applications are of value exactly because they can produce a realistic scenario without the presence of any real danger to soldiers or patients. It is arguably also this capacity for providing seemingly real experiences of actual, fictional, and fantastic places that gives VR its appeal with respect to entertainment applications. VR's ability to provide compelling illusions of virtual body-ownership has applications within a range of different domains beyond mere entertainment (e.g., allowing users become a fictional character). The ability to own a body

different from one's own could potentially inspire empathy towards others, and it also seems possible that virtual body-ownership illusions could be leveraged as an intervention or treatment in relation to body image disturbances.

Misperception of virtual distances and virtual walking speeds may pose a considerable problem with respect to some VR applications. For example, veridical spatial perception of distance, scale, and speed may prove to be a fundamental requirement in relation to certain training scenarios or visualization of architecture). Nevertheless, the limitations of human motion perception in VR have also been leveraged in order to compress larger VEs into smaller physical spaces. Most notably, a collection of techniques referred to as *redirected walking* makes it possible to scale, rotate, and curve the user's physical path by subtlety exaggerating or shrinking his real movements (Steinicke et al. 2010). Notably, other perceptual illusions and distortions have also been used to enable redirected walking. For example, Suma et al. (2011) proposed a technique that leverages change blindness illusions in order to move doors and hallways behind the user's and thereby produce overlapping virtual spaces.

Finally, vection is central to the creation of compelling vehicle simulators. Nevertheless, one should be cautious when presenting stationary users with virtual stimuli indicating self-motion. Specifically, this will introduce a visio-vestibular conflict which is believed to cause cybersickness (Davis et al. 2014). Thus, the factors that produce more compelling illusions of self-motion may also cause sickness on behalf of some users.

To conclude, VR systems make it possible to manipulate the senses unlike any traditional audiovisual media. Thus, VR is a near-perfect medium ripe for eliciting perceptual illusions. Moreover, perceptual illusions may serve as a useful tool for solving practical problems (e.g., enabling unconstrained walking in VR), and they may enable developers to provide more compelling experiences (e.g., the illusion of self-motion during vehicular travel). In fact, the presence response which is characteristic of VR is believed to result from the simultaneous occurrence of the place illusion and plausibility illusion.

Cross-References

- ▶ Cybersickness
- ▶ Presence and Immersion in Virtual Reality
- ▶ Redirected Walking
- ▶ Spatial Perception in Virtual Environments

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Peripheral Tangible Interactions

▶ Tangible Surface-Based Interactions

Peripheral Vision

▶ Spatial Perception in Virtual Environments

Persistent Environment

▶ Physical, Virtual, and Game World Persistence

Persistent State World

▶ Physical, Virtual, and Game World Persistence

Persistent World

▶ Physical, Virtual, and Game World Persistence

Persona 3 and the Lens of Surprise

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Synonyms

Role-playing game

Definitions

Role-playing game = a game genre where the player assumes the role of a character in their world.

History of Persona 3

Persona 3 is an interesting role-playing game, to put it simply. The game follows the story of a group of Japanese teens who each have a mysterious power; that being the power to summon a being known as a persona. A persona is a manifestation of a user's personality, which they can use to take down monsters known as Shadows, manifestations of a person's inner thoughts and emotions, usually being negative in nature. They can only use these powers during a secret period of time known as the Dark Hour, which takes place at midnight every night. While playing, the player has to juggle the characters' school lives and their mission to get rid of the Dark Hour at night. Looking at the game through the lens of surprise, the player will come across several moments of surprise.

In Jesse Schell's book *The Art of Game Design: A Book of Lenses*, the Lens of Surprise states that "Surprise is so basic that we can easily forget about it. Use this lens to remind yourself to fill your game with interesting surprises." The Lens of Surprise asks the following questions (Schell, 2019):

1. What will surprise players when they play my game?
2. Does the story in my game have surprises? Do the game rules? Does the artwork? The technology?
3. Do your rules give players ways to surprise each other?
4. Do your rules give players ways to surprise themselves?

Persona 3 has several twists in the story that many players will not see coming, including the death of a major playable character, the betrayal of the group's leader, and a major reveal that the group's efforts were actually having a negative

effect. The fact that the story is so deep and complicated will be a big surprise to anyone new to the series, which was common, as this was the first game in the series to mainstream attention.

For a more in-depth look at the death plot twist, during a botched operation to take out a powerful shadow, one of the characters, Shinjiro, gets trapped by a Shadow. Before anybody can do anything, the shadow kills him, shocking the team and the player, most likely. It comes out of nowhere with nothing hinting toward it. Another example; near the end of the game, it is revealed that in the process of killing all the powerful Shadows, the team unleashed a deity known as Nyx, who will come down at the end of January and bring an end to the world. The characters are informed that they can either have their memories erased of all the events so they can live in ignorant bliss until the fated day comes or they may keep their memories and search for a way to stop Nyx. These events are barely hinted at in the game, and they come as a complete shock for a new player. However, other than the story, there are no real surprises in any other areas of the game, with artwork, rules, and everything else being similar to role-playing games at the time.

With Persona 3 being a single-player game, the only way to experience the shock is by playing it. The battle mechanics can also be surprising to new players. Shadows will have weaknesses and resistances to various types of attacks, so the player might surprise themselves by trying a random attack and finding out it either has no effect or does extra damage against a shadow. The player can also surprise themselves by finding out various skills that fuse together into one, creating significantly more powerful skills.

Overall, while the rules of Persona 3 are, for the most part, unsurprising, along with the technology and artwork, the story has more surprises than most of its contemporaries, with jarring surprises happening frequently, keeping players on their toes.

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Personalized Content

▶ Experiential Media: Using Machine Vision and Sensor-Input to Create Dynamic Real-Time Generated Media

Persuasive Games

▶ Political Game Design

Pervasive Games

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Synonyms

Ubiquitous games

Definitions

The first academic definition for a pervasive game (Montola 2012) is provided by Schneider and Kortuem (2001), defining a pervasive game as "a LARP [live action role-playing] game that is augmented with computing and communication technology in a way that combines the physical and digital space together." In her pervasive discourse, Nieuwdorp (2007, original italics) highlights the ambiguity of the term "pervasive games" by listing the following meanings which she derived through a literature review (the reader is guided to her work for the sources of the review):

- A game that depends primarily on *pervasive technology and nonstandard input devices*
- An existing game that is *augmented by computers*, resulting in a blend of the real and virtual worlds
- A game that *pervades the real world in an undefined manner, and thus blends with it*

- *A specific setting* of the game world within the real world
- A game that *blurs the boundaries between itself and the real world*, which can influence the concept of the *magic circle*
- A game that is *an overlay* of the real world or where the *world becomes a game board*
- A game with a *persistent presence* in the real world, and thus available to the players at all times
- A game where the *gameplay* interacts with elements of the real world, thus challenging standard gameplay conventions
- A game where there is *mutual interaction among players and elements in the real world*
- A game that blends *with everyday experiences*

Nieuwdorp classifies these meanings into two perspectives: (1) "a *technological* one that focuses on computing technology *as a tool to enable the game to come into being*" (i.e., the first two meanings on the list above) and (2) "a *cultural* one that focuses on *the game itself and, subsequently, on the way the game world can be related to the everyday world*" (the last eight remaining meanings above).

Introduction

Although the origins of ubiquitous computing and pervasive computing differ (Nieuwdorp 2007), they are often used interchangeably (Nieuwdorp 2007; Montola 2012) and both are the basis for pervasive gaming (Nieuwdorp 2007). According to Montola (2005), "a pervasive game is a game that has one or more salient features that expand the contractual magic circle of play spatially, temporally, or socially," i.e., "expand the boundaries of play" (Oppermann 2009).

Pervasive games have been linked to a number of similar genres, such as: ubiquitous games; augmented/mixed reality games; mobile games; alternate reality games; (enhanced) live action role play (E/LARP); affective gaming; virtual reality games; smart toys; location-based or location-aware games; adaptronic games; crossmedia games; augmented tabletop games (Nieuwdorp 2007); and exergames (Stanley et al. 2011).

Staging a Pervasive Game

Ståhl et al. (2007) have identified three temporal phases in staging a pervasive game: "pre-production," "run-time," and "post-production." Because these phases concern games, these phases have also been referred to as "pre-game," "in-game," and "post-game" (Jonsson et al. 2007; Broll et al. 2006). The latter convention is used throughout this entry, reserving run-time to refer to when a game architecture is running and in-game to refer to when the game is running. In the pre-game phase, although resource demanding (Bell 2007), a game can potentially be adapted to each new staging (e.g., adapting to a new staging location (Oppermann 2009), i.e., supporting location adaptability). Adapting the game is done through reconfiguring the architecture and authoring content specific to each staging. Reconfiguration and authoring can continue into the in-game phase, provided it is supported by the architecture. In the post-game phase, an analysis of historic event data can be performed, players debriefed, and informed to the actual flow events (Stenros et al. 2007b). The results of a post-game analysis can inform further game design or stagings.

One of the driving factors why current game engines are ill suited for pervasive games is game mastering. Contrary to many video games, pervasive games do not necessarily run fully automatic. One or more persons, often referred to as *game master(s)* (GMs), can be assigned the responsibility of adjusting the game during its staging; an act which is referred to as *game mastering* (Jonsson and Waern 2008; Oppermann 2009; Montola et al. 2009) or orchestration (Thompson et al. 2003; Flintham et al. 2003a; Broll et al. 2006). A well-known role for a game master is that of a "puppet master": in charge and "pulling strings," all the while staying hidden behind the scenes (Jonsson and Waern 2008). Jonsson and Waern (2008) have argued that pervasive games benefit from being game mastered, e.g., allowing for: content to be actively authored to "fit the activities of the participants," the altering of game events, adjusting of difficulty, providing dynamic gameplay, or the reincorporating of user response back into the game (Jonsson

et al. 2007). Because pervasive games take place in the physical world, another responsibility of the game master is to keep players safe in the highly variable, possibly dangerous conditions of the physical world (Flintham et al. 2003a; Broll et al. 2006). A drawback of game mastering being that it can require a significant amount of human resources (Thompson et al. 2003; Flintham et al. 2003b). Jonsson and Waern (2008) have identified three needed functions, in order to successfully game master: (1) to be able to monitor the game, (2) make decisions about how the game should progress, and (3) have the ability to influence the game state.

Monitoring the Game

Players of pervasive games are mobile and out in the physical world. Two ways to monitor a player are: stationary hardware placed in the physical world (Stenros et al. 2007a; Jonsson and Waern 2008) or by giving players mobile devices to carry, interact, and communicate with (Jonsson and Waern 2008; Montola et al. 2009). The physical world affords seemingly infinite possibilities, meaning players are always able to produce "soft" events, outside the awareness of the game architecture, but still in relation to the game (Jonsson and Waern 2008). To capture some of these soft events, players can be monitored through direct surveillance and accounts thereof registered in game architecture (Crabtree et al. 2004; Montola et al. 2009). To assist in picking up on soft events, players can also be tasked with self-reporting, in the form of diaries (Montola et al. 2009; Jonsson et al. 2007).

Perhaps not part of the game state, per say, but important in monitoring a game mastered game, is any meta-level information, e.g., game master notes instructing other game masters on the state of the game (Montola et al. 2009).

Support Decision Making

To support game master decision making in-game, the potentially massive amounts of event information during monitoring must be dealt with. Additional information to aid decision making includes semistatic information, such as player information (e.g., photo, contact details, emergency information, game relevant skills) or documented help on how to stage a specific event (Jonsson et al. 2007). Automation aids game masters in decision making but obviously reduces game mastering, leading increasingly to a fully automated experience. One option to reduce game master load, without increasing automation, is to provide support tools, e.g., in the form of specialized GM interfaces or log analysis tools (Montola et al. 2009; Broll et al. 2006; Dow et al. 2005). Support tools convert or condense event information into a human consumable format. Another option is to cast nonplayer characters (NPCs) (Souza e Silva and Sutko 2009) in, to offload game master responsibilities (Jonsson and Waern 2008) achieving a more decentralized orchestration (Crabtree et al. 2004). Once game masters have made decisions, each decision must be actuated into the game.

Influencing the Game State

For a technology-sustained pervasive game, a common way to actuate change in a system, in run-time, is to directly alter the internal state of the game engine, i.e., alter variables in the game's data space (provided it is possible to access it) (Jonsson et al. 2007; Jonsson and Waern 2008; Hansson et al. 2007; Broll et al. 2006). Depending on the architecture, not all modifications are possible in run-time, and in such a situation the system must be brought offline to make necessary modifications (Hansson et al. 2007). Manually manipulating variables in the data space can be cumbersome when authoring lots of content. Developers of a game can attempt to anticipate what part of the data space game masters need access to and build an appropriate GM interface to it.

Although important for relaying observed events in monitoring a game, communication also plays an important role in influencing the game state, e.g., by pushing information directly to the players (Jonsson and Waern 2008). Communication can be either diegetic or nondiegetic (Bergström 2011), with the nondiegetic channel being particularly important to communicate out of the context of the game, in case of emergencies (Jonsson and Waern 2008). ("The 'diegesis' of a story consists of whatever is true *in that story*. Diegetic elements are 'in the story';

non-diegetic elements are not." (Bergström 2011, original italics)) Communication channels can be uni- or bidirectional.

State of the Art

There is a class of pervasive games, which are "technology sustained," relying on computer simulation to maintain game state and react to player activities; these games can be understood as "computer games interfacing with the physical world" (Montola et al. 2009, p.164). Technology-sustained pervasive games are contrary to "technology-supported" games, where not all game activities are supported by information technology (Montola et al. 2009), i.e., do not necessarily require a game engine. According to Broll et al. (2006), game engines for pervasive games do not differ entirely from computer games engines because "while the overall game is a mixed reality application combining the real [physical] and the virtual, the game engine actually does not need to be aware of this fact."

In a survey by Broll et al. (2006) important technologies for augmented-reality pervasive games have been summarized. Broll et al. (2006) mention the development of a pervasive game engine as "the logical next step," but, unfortunately, do not discuss the details of what constitutes a pervasive game engine, e.g., in relation to concepts such as persistence, interoperability, game mastering, and communication.

A recent survey, by Kasapakis and Gavalas (2015), aims to classify pervasive games into age generations based on technologies used. The survey is limited to 18 pervasive games, e.g., not containing tabletop games, smart toys, and trans-reality games, even though being mentioned as subgenres in the articles' related work. Kasapakis and Gavalas (2015) state that "the game engine organization model is largely dictated by the game scenario to be supported." If a general-purpose pervasive games engine is to be created, commonalities between game technologies must be found, e.g., support for a virtual persistent world. Kasapakis and Gavalas (2015) continues that the "current technological status favours [sic] always-on connectivity, hence, centralized models"; this is not entirely correct since, "always-on connectivity" relates to persistence, which can also be obtained through decentralized models.

In a recent publication by Kamarainen et al. (2014), the subject of cloud computing is discussed as a possible solution for pervasive and mobile computing, allowing the "end-user device to offload computation, storage, and the tasks of graphic rendering to the cloud." Kamarainen et al. remark that latency is the "main challenge" for cloud gaming, with most interactive games requiring response times that only "local deployment scenarios" can deliver. As a solution, they "propose to use [a] hybrid and decentralized cloud computing infrastructure, which enables deploying game servers on hosts with close proximity to the mobile clients." To exploit local resources, the Fun in Numbers (FiiN) platform features a distributed multitiered (i.e., four layered) large-scale architecture (Chatzigiannakis et al. 2011). The FiiN architecture supports more than one game engine, with each engine being the "local authority for each physical game site" (Akribopoulos et al. 2009). All game engines are coordinated by a centralized topmost layer.

The bottom layers of the FiiN architecture enable support for ad-hoc networks and Internet of Things (Gartner 2014). The problem with the FiiN architecture is that it is unclear exactly what types of pervasive games are supported. Pervasive games are defined in the FiiN publications as "games played in the physical space, indoors or outdoors, using mobile handheld devices, context-awareness, and in certain cases some degree of infrastructure and scripting." Chatzigiannakis et al. (2011) make no distinction between technology-sustained or technology-supported pervasive games, even though technology-supported pervasive games do not necessarily require a game engine, i.e., the infrastructure to enable them is very different. Akribopoulos et al. (2009, original italics) state that FiiN targets "mainly games that *involve multiple players, rapid physical activity, gesturing*, … *and less storytelling-based games*," which could account for why game master interfaces are not present in the architecture (Nevelsteen 2015).

Technology-Sustained Pervasive Games

Nevelsteen (2015) provides an extensive systematic review into pervasive games. Concentrating on technology-sustained pervasive games, a feature set is derived that describes characteristic features of a would-be pervasive games engine. These features can be considered a set of informal requirements from which a set of formal requirements can be drawn. Using the feature set, a virtual world engine was chosen as being in the same "product line" (Bass et al. 2013) as a would-be pervasive games engine, based on the shared trait of a persistence. The component feature set and the choice of a virtual engine as pervasive engine, by Nevelsteen (2015), are verified through the case study of the pervasive game called Codename: Heroes.

Component Feature Set

Having surveyed a total of 59 pervasive games/projects and 27 technologies, the following is a summary of the derived feature set for a would-be pervasive games engine (Nevelsteen 2015):

Virtual game world with world persistence: a spatiotemporal instance, with interacting virtual elements (at least one of which being the player); a game world that overlaps with both the virtual and the physical world; a world that continues to exist and develop internally even when there are no people interacting with it (persistence); and ubiquitous availability through a reliable architecture.

Shared data space(s) with data persistence: a common shared data space, with coordinated communication to it, and data persistence in the event of a shutdown or system failure, i.e., fault tolerant and recoverable.

Heterogeneous devices and systems: support for nonstandard input devices, comprised of sensors and actuators, that form an interface (Nieuwdorp 2005) between the player and the game; resolution of interoperability issues through a device abstraction layer; and the use of service-oriented architectures or the offering of such services.

Context awareness: context information, e.g., location, body orientation, available resources including network connectivity, proximity to surroundings or noise levels; context information is obtained through sensor enabled heterogeneous devices or service-oriented architectures; dealing with uncertainty in position localization or networking.

Roles, groups, hierarchies, permissions: various roles for player and nonplayer characters, organized in groups or hierarchies; different permissions or privileged information for the various roles or organizations, perhaps through an entirely different interface to the game.

Current and historical game state: including semistatic player info; a view of the current internal game state, e.g., through direct inspectable properties or through a specialized management interface; a historical perspective of the game state, e.g., through the logging of event data for post-game analysis; or any meta-level game information, such as game master documentation.

Game master intervention: the semiautomatic execution of the game through game master intervention in run-time, e.g., by directly manipulating the internal game state or through specialized interfaces, that potentially translate massive amounts collected game data into a human consumable form; game master intervention can be provide by a service-oriented architecture.

Reconfiguration, authoring, and scripting in run-time: in the pre-game phase (e.g., for location adaptability) that can be extended into the in-game phase; data-driven reconfiguration of software, hardware, and devices; dynamic story and content through content generation in-game; changing of the game rules through data-definition or run-time languages; autonomous agents; or the simulation of events for the Wizard of Oz (Dow et al. 2005) technique (see Section 2.3.8 of (Nevelsteen 2015)).

Bidirectional diegetic and nondiegetic communication: through various channels and/or interfaces.

Many of these features are quite generic (e.g., current and historical game state) and so are supported by engines in the domain of computer video games. Features more specific to pervasive games are heterogeneous devices and systems; context awareness; game master intervention; reconfiguration, authoring, and scripting in run-time; and bidirectional diegetic and non-diegetic communication, e.g., nondiegetic communication is required in a virtual world but not as pronounced as in a pervasive game where it is needed to cope with social expansion.

Challenges and Open Issues

The problems, caveats, and disadvantages highlighted through the case study of Codename: Heroes (Nevelsteen 2015) serve to highlight challenges and open issues for the creation of a would-be pervasive game engine. These challenges include: (1) using distributed and decentralized architectures; (2) extending ubiquitous computing; (3) interoperability; and (4) creating game master interfaces and tools.

Distributed and decentralized architectures: Exemplified by Demeure et al. (2008), fully decentralized architectures exist, where the game state is not centrally controlled and only shared with other clients when opportune. A challenge exists pertaining to the extent that a decentralized architecture can be utilized for games. Issues arise as how to: maintain security, maintain a shared data space, and prevent cheating (Yahyavi and Kemme 2013); gather and persist data (e.g., for monitoring); or build dynamic user interfaces. To deal with the scalability issue, virtual world engines already exist that use a centralized distributed system of servers for load balancing (e.g., BigWorld (2011)), so utilizing such techniques for pervasive games seems evident.

Extending ubiquitous computing: Devices and systems have the potential to offer richer context information for context awareness, e.g., the incorporation of body metrics or social relations. Ubiquitous computing remains a challenge, with open issues: increased utilization of context awareness; reduction of soft events (e.g., in communication); focusing on technology that can be effectively pushed into the background (e.g., for ubiquity of access and diegetic communication); and obtaining ubiquitous persona and presence (Dionisio et al. 2013). The latter recognizing that a player's identity is made up of the sum of their interactions with the game, e.g., crossmedia through different devices or interfaces. The amount of uncertainty in ubiquitous computing has been reduced considerably; early writings on pervasive games include much on mobile networking issues, which are solved in mainstream technologies today but some issues are still critical, e.g., losing connectivity by switching between WLAN and mobile networks. A partial solution could be that of delay-tolerate network communication, used in FinN (Akribopoulos et al. 2009), to obtain an eventually consistent game state in their distributed system.

Interoperability: In 2004, Greenhalgh et al. (2004) set out to interconnect heterogeneous devices with the EQUIP/ECT technologies. Broll et al. (2006) state interoperability in pervasive games to be a "well-known problem." And, a number of years later, Branton et al. (2011) dedicate an entire publication to deal with the "important challenge" of interoperability through standardization. Many innovations, such as new languages or middleware, are sited by Branton et al. (2011) as partial solutions, but compatibility between web services was noted as "largely lacking." Since some game engines and service-oriented architectures are already distributed systems, and they interact, then interoperability is an issue between heterogeneous distributed systems as well, i.e., similar to multi-cloud network communication (Singhal et al. 2013). Interoperability remains a challenge with the amount of heterogeneous devices and systems increasing and becoming more diverse (Gartner 2014).

Game master interfaces and tools: Because it is beneficial to build reusable game engines, it seems reasonable to infer that reusable game master interfaces and authoring tools should also exist (e.g., see (Broll et al. 2006)). Some game master tools have already been created (e.g., for mobile games (Paelke et al. 2008) and authoring tools for location-based games (Oppermann 2009)), but a

more general reusable approach remains a challenge (Guerrero Corbi 2014; Benford et al. 2009). Open issues are: capturing soft events and entering them in the game state; reducing the potential overload of data into a human consumable format; creating interfaces and visualizations that are applicable to a wide variety of games; and generating interfaces and visualizations that cater to the activity of game mastering rather than just presenting information.

Conclusion and Discussion

Computer video games have existed for decades, with reusable game engines to drive them; the major incentive for employing a reusable game engine being reduced development time and cost (Lewis and Jacobson 2002; Bass et al. 2013). Technology-sustained pervasive games can be understood as computer games interfacing with the physical world, so computer game engines can be used to stage a pervasive game (Nevelsteen 2015). Currently, there are no reusable game engines available for pervasive games, but herein a component feature set has been presented for a would-be pervasive games engine, including the challenges and open issues uncovered during the case study verifying the feature set.

According to Jonsson et al. (2007), pervasive games need a sensory system to monitor the physical world. Pervasive games are known to make use of "nonstandard input devices" (Nieuwdorp 2007), and with the rise of the Internet of Things (Gartner 2014), access to Internet of Things could potentially serve as such a sensory system. Considering the use of nonstandard input devices in pervasive games and the rise of the Internet of Things, how will this affect pervasive games remains an open question.

Cross-References

► Physical, Virtual, and Game World Persistence

References

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Phishing and Game Attacks

► Anti-phishing Attacks in Gamification

Phishing Attacks

► Anti-phishing Attacks in Gamification

Photogrammetry

► 3D Modelling Through Photogrammetry in Cultural Heritage

Physical Disabilities

► Making Virtual Reality (VR) Accessible for People with Disabilities

Physical Immersion

► Virtual Reality: A Model for Understanding Immersive Computing

Physical Prototyping

► Analog Prototyping for Digital Game Design

Physical Visualization

► Tactile Visualization and 3D Printing for Education

Physical, Virtual, and Game World Persistence

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Synonyms

Persistent environment; Persistent state world; Persistent world

Definition: "World Persistence"

Bartle, in 2003, stated that a persistent virtual world "continues to exist and develop internally even when there are no people interacting with it" (Bartle 2003). Bartle's criterion that the world "continues to exist" can be referred to as "world persistence" (Nevelsteen 2015), with the element of time, as a minimum, continually "developing internally" within the world, i.e., "a [persistent] virtual world cannot be paused" (Bell and Robbins-Bell 2008).

Introduction

In popular discourse, world "persistent" or "persistence" is often related to a feature to mean the continued existence of that feature, e.g., persistent storage meaning nonvolatile storage. This entry focuses on world persistence. Concepts such as world persistence and data persistence are often erroneously used interchangeably, and ambiguity creeps into the meaning of combined terms when using a particular word order, e.g., virtual-"world persistence" versus a persistent-"virtual world." If pervasive or ubiquitous computing is taken into consideration, which take places in the physical world, persistence once again can be used to describe the world. How this relates to other forms of world persistence is not well established. Various definitions and descriptions of "world persistence" exist (Bartle 2003; 2010; Girvan

2013; Bell and Robbins-Bell 2008; Lankoski et al. 2004a; James et al. 2004), but a clear overarching definition is lacking when taking into account the physical world. This entry isolates the concept of "world persistence" and discusses it in relation to the physical, virtual, and game world. The simulation of world persistence, namely, pseudo-persistence, is taken into account.

Physical, Virtual, and Game Worlds

To resolve the ambiguities around the usage of "persistence," the concept of "world persistence" is first isolated with respect to the physical, virtual, and game world.

Physical world persistence – Lankoski et al. (2004a) state clearly that "persistence is a quality of actual life and the physical world," i.e., the physical world has world persistence; it continues to exist and cannot be paused.

Virtual world persistence – In 2010, Bartle relaxed his persistence criteria, removing the need for internal development, stating: "if you stop playing then come back later, the virtual world will have continued to exist in your absence" (Bartle 2010). This is a logical step, because, beyond the element of time, "internal development" is a quality related to the "worldliness" of the world, rather than its persistence. Girvan (2013) states that world persistence is the "defining characteristic with which to distinguish between video games and virtual worlds." (It should be noted that virtual-"world persistence" is not the same thing as a persistent-"virtual world"; the latter being a virtual world that supports world persistence, which can be a tautology depending on the definition of "virtual world" used.) For their definition of a virtual world, Bell and Robbins-Bell (2008) use Bartle's original persistence criterion to differentiate between video games and virtual worlds, stating that "a virtual world cannot be paused." Lankoski et al. (2004a) corroborate the non-pausable criteria, stating "a game without a pause or ending is persistent by definition."

Game world persistence – Nieuwdorp (2007, original italics) derives that pervasive games can be discussed from two perspectives, a technological one "that focuses on computing technology as a tool to enable the game to come into being" or a cultural one "that focuses on the game itself." Using these two perspectives allows for another type of persistence to be identified, namely, "game world persistence" (Nevelsteen 2015). Technology can be created to maintain virtual world persistence (from a technological perspective), but designers of a world can explicitly choose to have certain events not to "continue to exist" (from a cultural perspective); game content is "reset" (Keegan 1997; Brennan 2009), so that it can be experienced repeatedly, e.g., in a persistent multiplayer game, having an important adversary stay dead keeps new players from experiencing that game content, so the adversary's death might be reset.

Other possible types of persistence related to world persistence are "data persistence," ensuring that "world" data is not lost in the event of system failure, e.g., in a world that "retains records of player data indefinitely" (James et al. 2004); "network persistence," maintaining a virtual connection between networked devices or systems that form a world, e.g., in a mobile networking setting; and "persistent activity," constant player activity under the influence of real world events, e.g., "bio breaks" (Nevelsteen 2015).

Pervasive Games and Ubiquitous Computing

Above it is stated that the physical world is persistent; since pervasive games blend with the physical world (Benford et al. 2005), pervasive games are persistent game worlds, sharing the trait of persistence with virtual worlds (Souza e Silva and Sutko 2009). In technology-sustained pervasive games (contrary to technology supported) (Montola et al. 2009; Nevelsteen 2015), it is sometimes beneficial "to exploit the coextensive virtual world as a 'behind the scenes' resource for

coordinating and managing devices and interaction in the physical space" (Greenhalgh et al. 2001). But, as explained in Nevelsteen (2015),

> in pervasive games, exact times of play (when the player is in the game world) can be expanded temporally, making times "remain uncertain, ambiguous, and hard to define" (Montola et al. 2009). A solution is to make the game world available at all times, as suggested by one of the definitions of pervasive games, "a game with a persistent presence in the real [physical] world, and thus available to the players at all times" (Nieuwdorp 2007). Another solution is to simulate world persistence, by either scheduling play times around when the world is unavailable or by making relevant player/world data available at least when those player(s) reconnect to the game (Söderlund 2009).

This means that if a pervasive game is technology sustained and the game is to be persistent, the technology needs to be available to the players when they want to access it (provided the game, from a cultural perspective, requires the technology to be accessible).

Related to pervasive computing rather than games, Lankoski et al. (2004a) state that the "nature of persistence is closely related to the nature of ubiquitous as understood in the ubiquitous computing research field."

Pseudo-persistence

A difficulty with identifying world persistence is that it can be simulated without raising awareness to the player. One example has already been given above; if the world is made available to players at all times they want to access it, it is seemingly always in existence; a straightforward way to achieve this is to have scheduled play times around downtimes (Nevelsteen 2015). Similarly, this access on demand can be applied to the events in the world as well. Söderlund (2009) describes a "pseudo-persistent" virtual world made up of a collection of mobile devices; world data is loaded and made available at specific times when players, relevant to that data, are playing. And, in a game, events can be generated during down times to simulate the passing of time (Wikipedia 2015; Nevelsteen 2015). Herein, I generalize the meaning of pseudo-persistent to mean the simulation of persistence.

Persistence in Practice

The Songs of North (Lankoski et al. 2004b) is a pervasive game (i.e., persistent in the physical world) that makes use of a coextensive persistent virtual world (the "spirit world"), as an invisible "behind the scenes" resource; the "spirit world and its physical counterpart thus share time and space" (Lankoski et al. 2004a). By logging in, a player can access the virtual spirit world, which was required to support world persistence. Lankoski et al. (2004a) state that "the game is possible to play without logging in . . .," i.e., the rules of their game dictate, from a cultural perspective, that their game can be played without logging in. What is problematic is that Lankoski et al. (2004a) continue by stating that ". . ., like any other persistent game: this happens for example when two players meet in the physical world or send an SMS or phone to each other." If from a cultural perspective, the virtual environment is deemed a critical resource for playing the technology-sustained pervasive game and that resource becomes unavailable (the environment does not support world persistence), then players trying to access that resource and failing would be interrupted in their persistent play.

Persistence is said to be the "defining characteristic with which to distinguish between video games and virtual worlds" (Girvan 2013). Player(s) of the video game called Doom (id Software 1993) have the option to pause the game, making the world fail to be persistent. But it would be trivial to remove this feature; would this altered version of Doom support world persistence? Typically player(s) of Doom, start their Doom client software, go through a load/log in procedure (with the world hosted on one of the player's systems) and enter the world. If all players stopped playing and shut down their

system, the world would obviously not persist, i.e., stopped as soon as the host was shut down. If Doom was left running, one might argue that Doom supports world persistence; however, the world state of Doom is only stored (i.e., data persistence) through manual player intervention. In the event of system failure, the world state would be lost, i.e., no world persistence. In a multiplayer game, if at least one player remained to keep the world running by manually persisting the data (with the other players coming back later to find the virtual world to have continued to exist in their absence), would the world be persistent? In this case, the definition by Bartle in 2003 is superior to that of 2010 because of the clause that there must be "no people interacting with it" (Bartle 2003). This allows Doom, which is kept alive through player interaction, to be classified as pseudo-persistent. Similarly, world persistence could be simulated, if all players agree on scheduled play times to access the world (i.e., the host would be available specifically during those times), but the world will be "frozen" during downtime. As a solution, pseudo-persistence could be used to give the illusion of a world "developing internally." It should be noted that it is almost impossible to have a truly persistent world; large-scale virtual worlds (e.g., World of Warcraft (Blizzard Entertainment 2004), which supports world persistence, with "instance" dungeons (WowWiki.com 2015) that are ephemeral) often have maintenance hours or days.

Bartle cocreated MUD (Trubshaw and Bartle 1978) and so it is assumed that his criteria were based on his own technology. Typically, the world of MUD is hosted on a server with players accessing the world through networking. Ideally, the world is then continually in existence and available, with players unable to pause the world, i.e., MUD supports world persistence. It is possible to access a MUD from a local machine as a single player game; although not the intended use, it is possible to compare MUD and Doom this way. When MUD is used locally, if the player shuts down the computer, the world will be frozen, similar to Doom (this could be considered a maintenance break). The major difference between Doom and the local version of MUD with respect to the world persistence definition is that MUD still does not support the pausing of the world and MUD periodically stores the world state (i.e., data persistence), guaranteeing world persistence if the computer is left running.

Above, a world where certain events are reset periodically is said to lack game world persistence for those events. Taking this to the extreme is what has been referred to as a Groundhog Day MUD, "where all the elements of the MUD's world (excluding the users [players]) are reset to some predefined state" (Keegan 1997). This is a borderline case, which can be solved by asking the question, is there something in the world that is and has been under the constant influence of the world's time? If everything in the world is reset, excluding the player data, then the player data has game world persistence, but the world lacks persistence. The world would be equal to the concept of an instance in existence today, which explicitly does not support world persistence. The separation of world and player data is more distinct in the multiplayer game of Diablo (Blizzard Entertainment 1996), where players first gather in a virtual lobby, before venturing into instance dungeons. The dungeons are created for one play through and reset, but player data is preserved; afterwards players are sent back to the lobby where they can choose to start another dungeon. Diablo can be classified as pseudo-persistent, where the virtual lobby supports world persistence and player data is loaded in the instance when relevant players are playing. Having player data persistent is perhaps equal to what Lankoski et al. (2004a) refer to as "persistent game identities."

Conclusion and Discussion

This entry isolates the concept of "world persistence" and discusses it in relation to the physical, virtual, and game world. The simulation of world

persistence, namely, pseudo-persistence, is taken into account.

Cross-References

- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Pervasive Games
- ▶ Virtual Reality
- ▶ Virtual World, a Definition Incorporating Distributed Computing and Instances

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Physics Engine

- ▶ Game Engine
- ▶ Game Physics Engine, Overview

Physics Simulation

- ▶ Cellular Automata Methods
- ▶ Lattice Gas Cellular Automata for Fluid Simulation

Physiological Monitoring

▶ Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring

Pipeline

▶ Pipeline of 2D Vector Animation in Television Series

Pipeline of 2D Vector Animation in Television Series

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Synonyms

2D animation; Digital process; Digital production; Pipeline; Vector

Definition

Pipeline is commonly used in animation production processes; it describes the process of working on a piece, episode, or film. It explains the route that the production follows to be able to carry out and finish, through the different departments involved.

Introduction

To understand the processes of 2D vector animation, it is necessary to take into account the historical evolution of the technical advances that have allowed an advance in the animation series.

Hanna and Barbera allowed us to create a streamlined pipeline for animated television production, clearly specifying the processes to be followed in order to optimize the production times required by television.

The advent of digital techniques has made it possible to speed up production processes and reduce budgets. In addition, a favorable result has been obtained in the creation of new visual styles in the 2D animation series, leaving aside Hanna-Barbera's compact designs.

Background and Technical Evolution

The origins of digital animation lie in the history of technical development itself. The interest in making moving images helps the technical development of cinema. Animation is born as an almost handmade process, which evolves to digital, but without losing the artistic aspect.

The first known attempt at a projection animation dates back to 1640, when the German Athanasius Kircher invented the magic lantern. Kircher made drawings on glass plates that he projected, thanks to the new invention. He added position changes on the characters, like a man who slept and opened and closed his mouth in a mechanical way (Garcia 1995).

As a reference for entertainment animation, the first optical toys such as the zoetrope (It consists of a cylindrical drum that restores the continuous development of a repeated action. A strip of paper is placed inside the drum, the length of which is equal to the perimeter of the inner circumference of the drum. The strip is drawn with a figure broken down into phases of movement, as many as there are slots in the drum. The drum rotates around its center, and looking through the slots, you can see how the various drawings acquire movement.) or the praxinoscope ("The purpose of the apparatus is to obtain the illusion of movement, not limited to the repetition of the same gestures in each turn of the apparatus, as is necessarily the case with all known apparatuses: zoetropes, praxinoscope, etc., if not the contrary, having an indefinite variety and duration and thus producing true animated scenes of unlimited development (Beaudet 1982).") were created. Both devices represent the phases of a short cyclic

movement. This technique is the same as the one used in digital GIF (Graphic interchange format (GIF) a system of compressing the information of a digital image employing a restricted palette to reduce its file size.) files or in the animation sprites (Chong 2010, p. 120) used in videogames. In 1877 Emile Reynaud created a praxinoscope with a tape of longer images, which allowed her to create animations with a plot.

> In these tapes he already used modern cartoon techniques, such as the dissociation of figures and decorations, successive casts on transparent sheets, etc. We can say, then, that the cartoon was born before the cinema itself. (Gutierrez Espada 1979)

With the arrival of the cinema in 1885, thanks to the Lumière brothers, a camera was used to record the images, and Alfred Clark introduced the handwheel system, which took images frame by frame. With this technique, Emile Cohl (Furniss 2008, p. 130) makes a series of works through drawings in front of the Fantasmagorie camera, where the author simplifies, schematizes, and iconizes the characters with the need to reduce the work to be done. Winsor McCay (Bendazzi 2002) works directly on paper, fitting the sheets into a box, to prevent inter-frame movement, reusing drawings of poses and movements.

John Randolph Bray, another cartoonist, discovers the industrial possibilities of cartoons. In 1913, in the artist's dreams, he introduced a new technique, he knew the repetitive printing used in newspaper presses, and applied it to the printing of backgrounds in order to later draw the animation of the characters, saving the redrawing of backgrounds. In 1915, together with Earl Hurd, they patented the "cel system" (Laybourne 1998). The system consists of carrying out the animation on transparent cel to be recorded on top of the backgrounds. This technique has been used until the computer age. The acetate technique separates the work from the animation and the backgrounds and therefore provides a specialization. In the cel the paper drawing is traced and then filled with opaque paint, all this by dividing the work by departments.

If we look at the first designs of the characters, they all look like rubber, with very soft bodies. Pat Sullivan and Otto Messmer with Felix the Cat, Max Fleischer with Betty Boop, and Walt Disney with Mickey Mouse, among others, are characters who have a base of circles and round shapes that allow them to move their movements dynamically and give them that rubber character, called Rubber Hose, imitated in 2017 in the video game Cuphead (https://www.cartoonbrew.com/videogames/cuphead-overflows-classic-cartoon-surrealism-153824.html).

Another of the techniques that particularly stands out in the early years is the one used by Lotte Reiniger (Furniss 2008, pp. 237–238) in 1926, with *The Adventures of Prince Achmed*, which, based on shadow theater, produces an animation of black silhouettes on a white background. This technique requires that all the different parts and movements of the characters are generated, and then the performance is done under camera. This technique, at the moment of digitalization, is now called puppet animation, with all the advantages of digital technology.

In the early 1940s, the UPA (Amidi 2006) studio was created, where they began to create more schematic animations and simplified and easy to animate characters. All this makes it possible to adjust to postwar budgets, and this influences the use of simpler visual resources that show more aesthetic pieces. This new style of animation influences artists such as Chuck Jones in Warner or the limited animation series that Hanna-Barbera has been producing for more than 30 years.

On the other hand, the first experiments with animation and soundtracks by John Whitney arrived. In 1961 he presents Catalog (Chong 2010, p. 164), a piece of complicated optical shapes made frame by frame. Whitney argued that technological innovation will provide us with the means to develop a new audiovisual. Computers are the only instrument that allows us to create music related to graphics and colors in motion, although their complementarity is still experimental, but good results are expected.

> The synthetic image, which is so because it only exists in the electronic memory, and is reflected in its high-definition graphic output, when programmed for this purpose, allows the creation of a dynamic reference of space and object, in which

> every image and every creative will on it is possible. (Eguillor 1986a)

The technical advance continues in 1985 with Disney and introduces the video cameras to perform linetest (Filming of the animation in its first stage of production. Call also 2D pencil test.) and the APT (animation photo transfer) to scan the drawings. With the Disney CAPS (Computer Animation Production System) software, the scanned drawings were transferred to digital ink and paint, making the process easier. This software is developed by Pixar on behalf of Disney. It is used to scan and paint each drawing. To all this we must add the creation of other professional animation software, such as Animo, RETAS or Toonz, that follows the Disney CAPS and is standardized in animation production. All these systems take the digital treatment as much as has been possible until now in analog animation: multiplane, sound, or overlays. New technologies open up new ground for artistic creativity:

> We will have to wait for the not too distant future, and thanks to this, the cartoon field will reach a level of artistic consideration that it has only achieved on a few occasions. Although it won't be exactly cartoon as it is normally considered. Although the process of the synthetic image is analogous to that of the animation (the brain does screen readings on the screen, as in frame by frame animation), I think it is necessary to talk about computer image processing rather than cartoon, with a plastic quality as good as paint. (Eguillor 1986b)

Macromedia Software created FreeHand and Flash design programs based on vector graphics in the 1990s. FreeHand is dedicated to graphic design, and Flash is dedicated to creating simple animations for the web using vector images with an interactivity component. It allows drawing in a very intuitive way for the user; in the same way, it works with frames, allowing simple animations and a few megabytes that can be shared on the Internet. In the early 2000s, Macromedia joined the Adobe group, which continues to develop the tool. Years later, vector animation tools such as Toon Boom or Anime Studio Pro were created. The arrival of graphic tablets, which allow drawing on the screen, has brought a breakthrough in the processes of drawing, design, and animation or design, which allows us to draw directly on drawing, animation, or design software, on macOS, or Windows systems.

In the late 1980s and early 1990s, television consumption increased, and this created demand for the cartoon product (Holz 2017). The worldwide spread of the personal computer and user-friendly animation software opens a new path. Lowering the costs of creation and facilitating accessibility, distribution and exhibition through the Internet. We can say that there has been a second revolution in animation as with the advent of sound and color. Technology continues to advance and cartoons have always been on a par. Any technical advance was soon used in the industrial products of the environment. By solving certain phases of the production process, the technology allows the team to spend more time on other, more aesthetic or stylistic facets of the production process, giving a wider margin in the visual sense. A clear example in Cartoon Saloon's Puffin Rock series (https://blog.smithmicro.com/2015/10/06/anime-studio/how-anime-studio-is-used-to-produce-the-show-puffin-rock/).

Production Pipeline with Vector Animation

The realization of an animation series follows the basic guidelines: preproduction, production, and postproduction. The use of vector technology allows you to modify processes that affect time, costs, and visual styles.

Preproduction Stage

In the preproduction phase, we start with a budget to develop the series. The pilot episode has been conducted earlier to secure the necessary financing; otherwise, it would not be possible. The production team distributes all the work to be done on a production schedule, drawing up a list of all the necessary human and technical resources. With the help of the entire team, the premises for each episode are established so that they can be developed by the script teams, as the design team begins to develop the characters and props. In a traditional animation production (handcrafted or digital), the reference material that is generated on

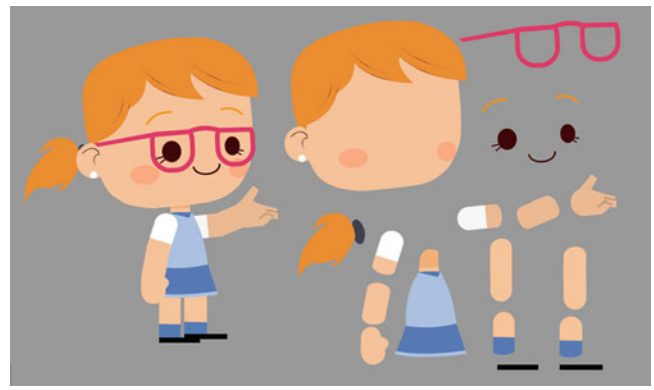
paper and then scanned and colored in digital, or also in digital form, serves as a visual reference for animators, but that material is not reusable. But in a vector production, the development is much more detailed. The art director's team, along with the director and animation supervisor, establish the visual and style guidelines to be followed. The design team not only makes the designs but also animates and demonstrates how the characters should be moved. In this way they generate a whole library of digital files of characters, props, and movements, which the animators use throughout the series, following the style set by the director and art director. These are guidelines that are followed when designing the characters, to optimize the animation during the production phase.

- The character design is broken down into layers or levels of each part of the body. Any character in the series looks like a united whole, but has parts to animate (Fig. 1).
- Reuse of the parts of the body is only drawn once, hence the importance of preproduction, to make all the material required in character. The characters function like puppets. The animator is dedicated to the animation of the expressiveness without the need to draw.
- Careful planning and attention to detail are marked from the development of each character and should be reflected in the visual guide. The character in his visual development has been raised how the character will move its parts and its limbs.
- Simplified, cyclical backgrounds and straight sections. With vector drawing tools, backgrounds are created with loose elements, making it easier to reuse or change the color of the scene (Fig. 2).

Cyclic or repetitive backgrounds are those that are seen on the screen in a race that are repeated elements every so often; again using the editing tools, you can break this repetitive action (Fig. 3).

When creating a long background, we must introduce different elements along the background. Each time the movement cycle changes, we vary the elements to make it different each time (Fig. 4).

- Walking or running cycles are simplified. Any cycle or animation that can be reused. The walking cycles are carried out with few poses, achieving the sensation of movement (Fig. 5).
- The main use of the characters' views is the ¾, which allows better transmission of the characters' expressions and actions.
- Lip sync is designed with a limited number of phonemes, with no intermediate drawings (Fig. 6).
- The use of squash and stretch (It is one of the 12 principles of animation. The exaggeration and deformation of bodies and other parts, as if they were flexible, serve to achieve a more comical or more dramatic effect. Stretching also helps to give a feeling of speed or inertia.) can be a good expressive resource and sometimes helps the expressiveness of animation (Fig. 7).



Pipeline of 2D Vector Animation in Television Series, Fig. 1 Character in parts

Pipeline of 2D Vector Animation in Television Series, Fig. 2 Background base design

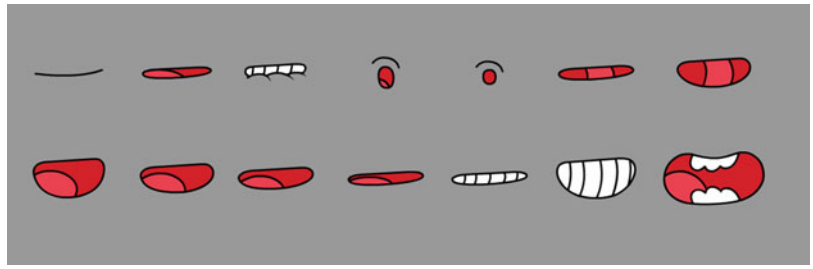
Pipeline of 2D Vector Animation in Television Series, Fig. 3 Background mount to repeat

Pipeline of 2D Vector Animation in Television Series, Fig. 4 Elements to make a background

- The design of trousers or legs of a single color, to make fewer drawings in the animation. Some of the supporting characters use this method.
- The character design becomes symmetrical and is easy to reuse. The introduction of asymmetrical characters as protagonists shows an advance in limited animation (Fig. 8).
- The visual entity marked by the limited color palette is always necessary and gives a unique character to the series.
- Special effects such as water, fire, liquids, etc. are defined graphically and animated.
- Simple animation as a way of life for a character, such as blinking or a simple gesture, is reflected in any scene (Fig. 9).

The Amazing World of Gumball, Samurai Jack, and Teen Titans Go! are some of the series that show an aesthetic, a very refined animation, very graphic, full of elements that can be animated without limitation.

Pipeline of 2D Vector Animation in Television Series, Fig. 5 Simplification of walking



Pipeline of 2D Vector Animation in Television Series, Fig. 6 Different mouths to lip sync

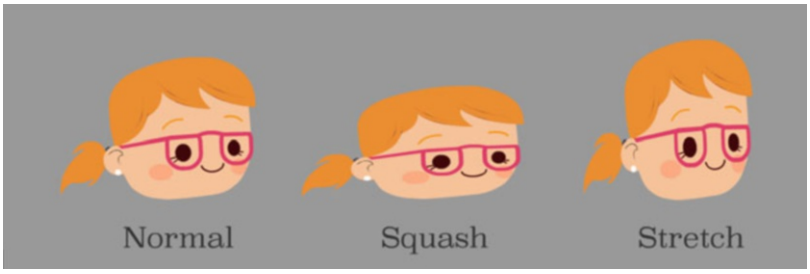
While all the design material is being produced and the scripts are being finished in stages, the reference dialogues, which are used in the creation of the storyboards, are being recorded. In the new animation series, the storyboarding phase is created directly with a drawing software, which allows you to work with the audio of the dialogue, and introduces more drawings of poses, camera movements, and other functions, which make it easier to create the episodes more dynamically. The piece that is obtained is an animatic (Is a series of still images edited together and displayed in sequence. More commonly, a rough dialogue and/or rough soundtrack is added to the sequence of still images (usually taken from a storyboard) to test whether the sound and images are working effectively together.), essential for the next phase, since it gives us as a result of the number of scenes divided by each episode, with all the characters, props, and backgrounds that intervene in the scene, including the reference audio of dialogues. In this phase we finish defining all the necessary backgrounds for each scene, designing each detail that intervenes in the action.

In this phase, all the necessary backgrounds are defined for each scene, designing every detail that intervenes in the action.

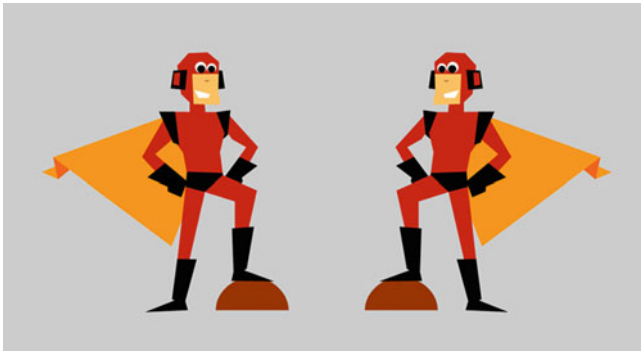
Production Stage

In this phase the technical layouts are made; these consist of generating the vectorial animation files, which are for each scene, adding all the necessary character libraries, props, backgrounds, and audios. The layout artist composes the scene with the reference material, so that it is ready for the animator.

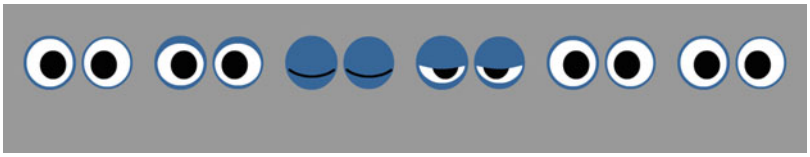
In the animation process, the animator is assigned a number of scenes to perform. The professional has all the material provided in the files generated in the layout but also has the visual and animation guides generated by the animation director in the preproduction stage.



Pipeline of 2D Vector Animation in Television Series, Fig. 7 Applying the squash and stretch to a head



Pipeline of 2D Vector Animation in Television Series, Fig. 8 Symmetrical character



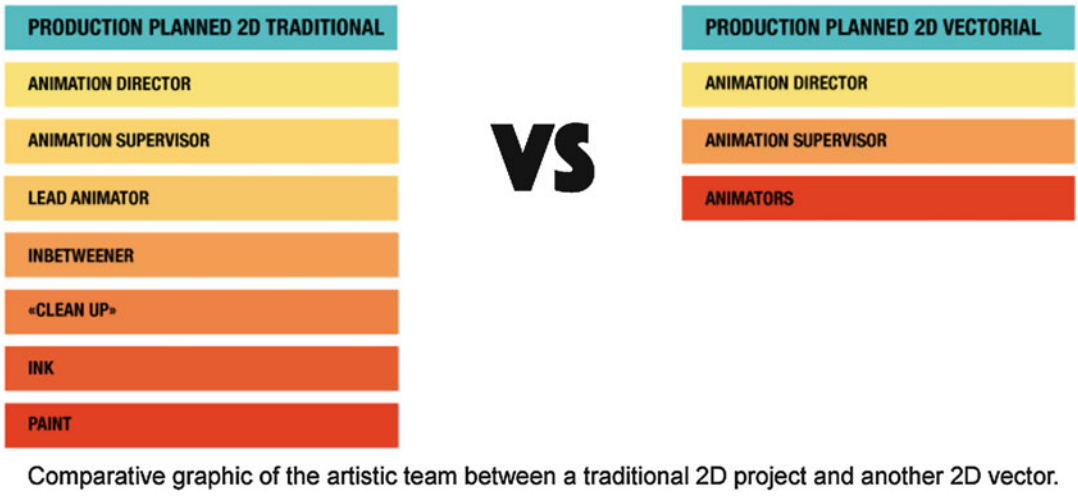
Pipeline of 2D Vector Animation in Television Series, Fig. 9 Frames of blink eyes

The vector animation process can be done by two ways:

1. One way is the traditional digital system, also known as tradigital, which follows the traditional processes but on vectorial drawing with animation software. The animator can use the material generated in the preproduction, to maintain the visual style. These animators are called key animators. This method will have a subsequent process of cleanup and final coloring that is carried out by an animation assistance team, which finishes the visual finishing of the scenes.
2. The other way used is known as puppet animation or digital cutout. The animator makes the scenes with all the preproduction material, does not have to draw, only animates the parts of the characters and objects, also makes the camera movements, and uses the effects that are in the library. The times of realization are shorter than with the traditional technique, since they have only one phase, and the scenes go directly to postproduction.

Postproduction Stage

The scenes of each episode are edited. The necessary sound effects are added to enhance the action and continuity of the scenes. If the previous dialogues are for reference, the final ones are recorded, to be mounted with the scenes. If the production of the series is more visually complex, a compositing process is performed. This consists of composing the scenes with the different layers, more complex camera movements, visual lighting effects, or FX. The music that accompanies each sequence is then performed, which is mixed with the episode, obtaining the master of the episode.



Pipeline of 2D Vector Animation in Television Series, Fig. 10 Production traditional 2D versus production digital 2D

Conclusions

The technological development has been present throughout the history of animation; the current use of digital tools allows professionals to have a better general concept of an animated production. This greater concept is reflected in a greater knowledge of the work and is therefore an advantage when it comes to carrying out a series of this type. The traditional animation production method has benefited from the technical advances brought about by the market:

- New animated cartoon channels have been created on TV and the internet.
- New studios have been founded, with new series proposals.
- 2D animation has been established in broadcasting channels.
- Development of 2D vector graphics and animation software.
- The search for new esthetics in animation.

The new technologies in animation have allowed a quick adaptation of the traditional 2D animation to the 2D digital animation, showing certain conclusions, which definitely show an advance in the sector and show a new way in the development of series (Fig. 10).

- The technical advances have allowed to reduce the times of production and to optimize processes, improving the quality of the productions.
- 2D software requires multifaceted artists to work as a team in the creative process, totally involved in the work flow.
- It requires detailed planning of the production in order to optimize resources and means. Good planning allows resources to be reused and so more efficient productions.
- The fundamentals of traditional animation are transferred to digital productions to further the evolution of the technique.
- Strategies and character design resources are established to make them easier to animate. Material is created with the idea of it being reused.

Cross-References

► Vector Graphics

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Pixel

► Color: Pixels, Bits, and Bytes

Planetary Generation in Games

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Synonyms

Asset creation; CG; Computer graphics; Procedural content generation; Virtual environments; Virtual reality

Definition

Creating large amounts of playable content is a problem that game developers often face when creating large-scale games. One approach to address this challenge is to program the computer to assist in creating this content, a method generally referred to as procedural content generation (PCG) (Freiknecht and Effelsberg n.d.).

Introduction

Virtual game worlds for modern video games are requiring constantly increasing time and resources to create this ever-increasing amount of content. Being able to procedurally assist the creation of such content can allow the creation of large environments of high detail and fidelity, which would be otherwise impractical to handcraft manually (Freiknecht and Effelsberg n.d.).

Generally, the procedural generation of content in different forms and small scale is established in the industry; however, not much work has been done in the field of creating and managing very large worlds such as entire planets (Carpenter 2011).

Procedural Generation Overview

Procedural generation is a computing method of creating data algorithmically, instead of manually.

This is usually achieved via a combination of human-created content and algorithms, combined with computer-generated (pseudo) randomness and processing power. In computer graphics or animated movies, it is often used to create 3-D models and textures (Ebert 2003).

In video games, it is typically used to help create larger amounts of content in a game, such as virtual landscapes, 3-D objects, character designs, animations, or non-player character dialogue. Depending on the implementation, advantages of procedural generation can involve generating larger amounts of content from a smaller file size and a smaller amount of input data, reduced manual work and (pseudo)randomness for gameplay variation (Eurogamer, Digital Foundry, Star Citizen Tech Focus, seamless scaling from gas giants to detail-rich alien worlds n.d.; PCGamer, Elite Dangerous n.d.; Structure system procedural generation n.d.; The BLDBLOG book, Procedural destruction and the algorithmic fiction of the city n.d.).

Driven by the need of making games more replayable, to reducing time and resource burden as well as to generate unique virtual environments, many Procedural Content Generation methods have been devised (See Freiknecht and Effelsberg n.d. for an overview).

A recent exciting evolution is the combination of Machine Learning and Procedural Generation. While researchers are redesigning methods from machine learning (ML) to solve PCG problems, the ML community has been inspired by PCG methods to solve a particular set of problems, in this context new opportunities such as procedurally generated learning environments. Although their origin can be traced back to games, we believe (procedural) generation algorithms can play an important role in creating more general machine intelligence (Increasing generality in machine learning through procedural content generation n.d.).

Large-Scale Generation in Games

There are several challenges to creating very large game worlds of planetary size.

One of the main problems is being able to produce far more content than could be physically stored in the memory, but doing so in such a way as to only generate on-demand what is needed around a given location, in order to minimize cpu, gpu, and memory utilization (Greuter n.d.).

Since the world size vastly exceeds what can be represented using 32-bit floating points numbers, precision becomes a large issue. On-demand collision/physics generation on client and server also needs to be implemented, since the collision representation for the environment is too large to be stored in the memory (Planetary generation and tools n.d.).

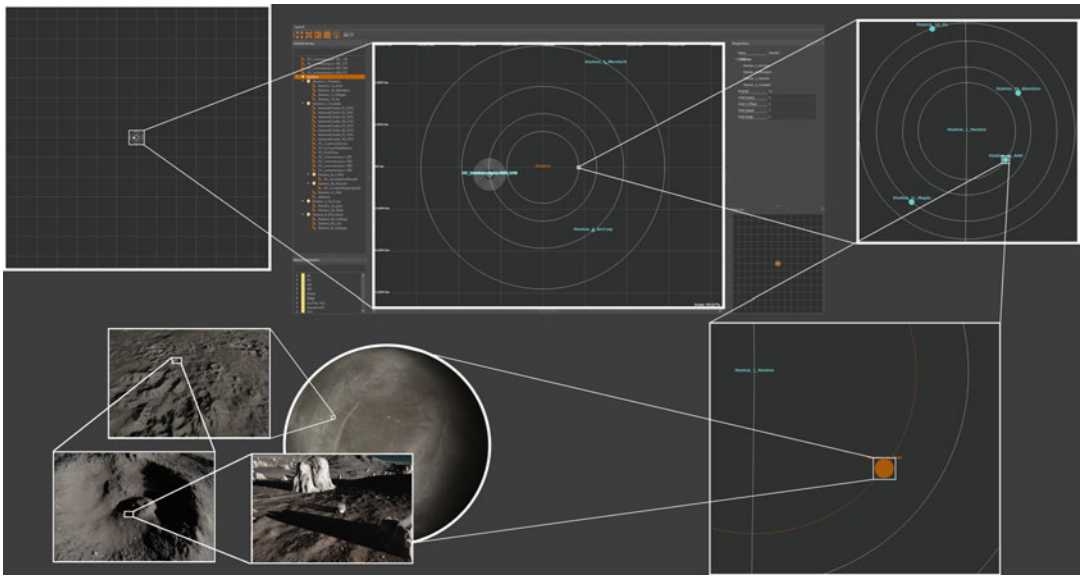
Planetary Generation in Games

A long-standing goal of planetary generation is to achieve seamless transitions between space and planets: fly to a distant planet, landing on it, getting out, and exploring its entire surface with no loading screens (Eurogamer, Digital Foundry, Star Citizen Tech Focus, seamless scaling from gas giants to detail-rich alien worlds n.d.; PCGamer, Elite Dangerous n.d.).

This process also requires the creation of custom planetary generation tools, to provide artists enough control over the planet's creation, but still having the process as much automated as possible due to the sheer size of the environment (Designing with Autonomous Tools: Video Games, Procedural Generation, and Creativity n.d.; Planetary generation and tools n.d.) (Fig. 1).

Conclusion

Currently, there are few games implementing planetary-scale generation and seamless transition from space to the planet in an online environment (Eurogamer, Digital Foundry, Star Citizen Tech Focus, seamless scaling from gas giants to detail-rich alien worlds n.d.; PCGamer, Elite Dangerous n.d.; Procedural Generation, No Man's Sky n.d.). As described in this article, this is typically achieved through a combination



Planetary Generation in Games, Fig. 1 Planetary Generation. Showing the sense of scale, seamless transition, and scaling from a solar system in open space down to planetary surface details (Eurogamer, Digital Foundry, Star Citizen Tech Focus, seamless scaling from gas giants to detail-rich alien worlds n.d.)

of procedural generation, tools, and human-driven input.

As games are striving to take place in progressively larger open-world environments, the generation of planets and associated ecosystems constitutes a promising branch of research and business development opportunities, especially when combined with recent machine learning approaches.

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- ▶ The New Age of Procedural Texturing
- ▶ UV Map Generation on Triangular Mesh

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Platformer

► Sonic Adventure 2, an Analysis

Play Space

► Games and the Magic Circle

Playability

► Player Experience, Design and Research

Playbor

► Game Prosumption

Player Abusive Behavior Detection

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Synonyms

Player behavior; Toxic behavior

Definition

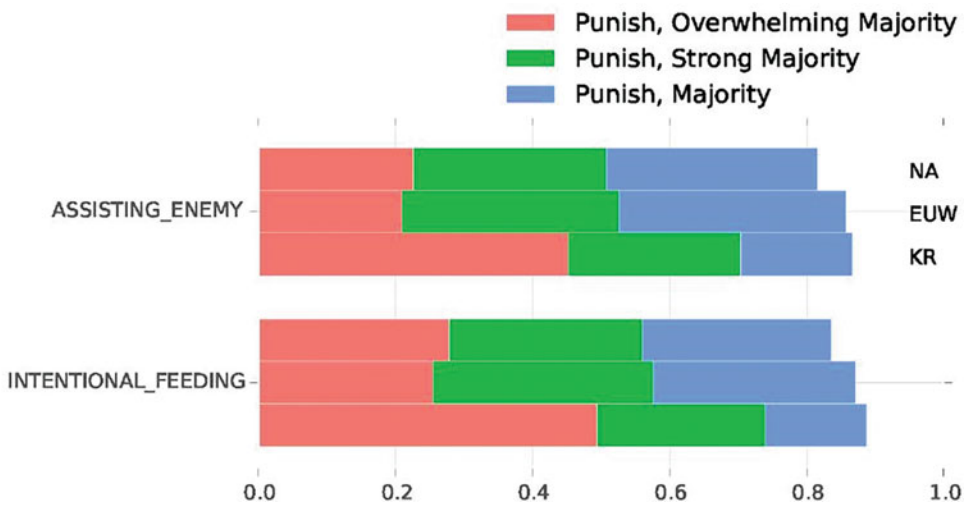
Player behavior = The way a player acts and conducts themselves within a game.
Toxic behaivor = A player's behavior within a game causes harm to other players by psychological or mental means.

Introduction

Antisocial behavior that can have lasting effects and to which numerous players are exposed to is often called *toxic behavior*. In a nutshell, online interactions are different than in the real world: Many of the social cues and hierarchies that dictate decorum are not present online. These different norms, for example, asynchronous communication and anonymity, are thought to reduce the typical social barriers against abusive behavior via a phenomenon known as toxic disinhibition. That is, when online, we are more willing to behave like jerks. When coupled with a competitive environment, e.g., eSports and other competitive multiplayer video games, this often results in outlandish behavior that would be completely unacceptable in face-to-face interactions. Understanding, detecting, and combating toxic behavior is a challenging task; however, there have been some noteworthy developments in the past few years.

Understanding Toxic Behavior

Toxic behavior is a complex subject. It became a part of the general gaming lexicon in large part due to MOBAs. The authors of (Kwak et al. 2015) analyzed almost 11 million reports of 1.4 million alleged toxic players from six million matches of League of Legends. They found statistically significant difference between how different cultures ("Western" vs. "Eastern") recognized and punished toxic behavior. In particular, they noted that Eastern cultures were much more likely to punish players that harmed their own team, whereas Western players were more likely to punish toxic players that attacked other players.



Player Abusive Behavior Detection, Fig. 1 The percentage of reports for behavior that directly affects the result of the match for each region that results in a punishment

Figure 1 shows the percentage of reports for toxic behavior that might directly affect the outcome of the match, broken down by how many instances resulted in punishment per region. An explanation for this observation is that Eastern cultures are "collectivist," i.e., behavior that directly caused harm to the team is anathema while being tolerant of abuse targeted at poorly performing players.

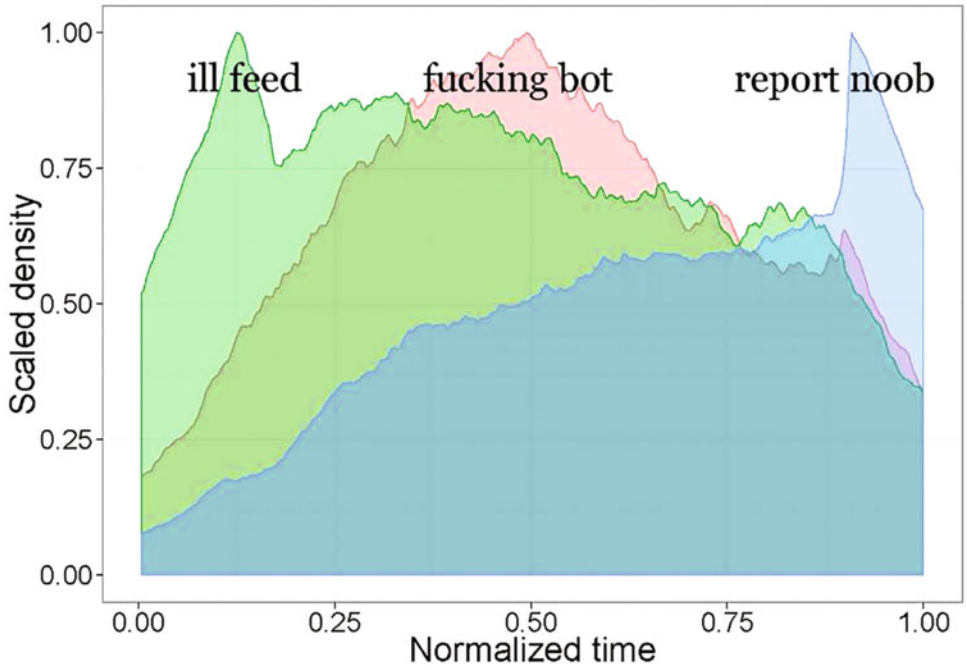
Detecting Toxic Behavior

The most common way of dealing with toxic behavior is the use of player-driven report systems and manual review. Report systems usually come into play after a match has been completed, where players are given the option of reporting another player for toxic behavior. Typically, players are given several categories to report the behavior under, as well as an optional text field to supply any additional details. Report systems are useful in that they allow players that directly experienced the toxic behavior to provide context for game developer support staff. Unfortunately, they rely on players to take the initiative, and as indicated by Kwak et al. (2015), the majority of players do not report toxic behavior in matches where it was later deemed to be present. This is likely due to the *bystander effect,* which is humans' tendency to assume someone else will help. Interestingly, however, Kwak et al. (2015) also found that explicit pleas for other players to report seemed to break through the bystander effect, resulting in an increased number of reports. The major downside to report systems, however, is that they require a lot of human effort for game developers. Invalid reports must be filtered, and human intervention is expensive and time consuming; ideally, automated systems can help out in this respect.

When it comes to automated detection toxic behavior, there are two general approaches: (1) use *domain-specific* techniques and (2) use more *generalizable* techniques.

Domain-specific techniques are those that take into account features that are specific to a particular game or genre. For example, toxic behavior in MOBAs often takes form as intentional feeding, i.e., a player deliberately dying to the enemy team which confers an immense advantage due to the in-game economy. An automated detection mechanism might aim to discover disproportionate kill/death/assist ratios, or even go so far as to detect deliberate in-game movements indicative of intentional feeding (e.g., the toxic player running in a straight line at the enemy team).

Generalized techniques aim to extract features that are common across all games. The primary example of a generalized technique uses chat logs,



Player Abusive Behavior Detection, Fig. 2 Early-, mid-, and late-game bigrams used by toxic players in the League of Legends, normalized over the length of a match

probably the most common manifestation of toxic behavior. Here, recent advances in natural language processing can be used, but even simple techniques have proven to be effective.

One of the earliest attempts to build an automated system for detecting toxic behavior made use of both techniques. The authors of (Blackburn and Kwak 2014) built a classifier to automatically detect toxic behavior in League of Legends. They extracted a variety of both domain-specific and generalized features and used a random forest classifier to determine whether players were guilty or innocent of toxic behavior. In the end, they were able to distinguish between guilty and innocent players about 90% of the time and found that even simple features extracted from chat logs (e.g., the valance or "goodness" of in-game chat) were effective. Unsurprisingly, they found that a model built on North American dataset and applied to European data was much better than random, but weaker, primarily due to reduced effectiveness of the chat-based portion of the classifier.

Conclusion

Toxic disinhibition is an unfortunate reality of online interactions. However, just like cheating, toxic behavior can be addressed. Research indicates that there are regional differences in how toxic behavior is viewed expressed, and thus developers should consider tuning their systems to the demographics of their players. Further, the efficacy of report systems might be increased by simple UI changes prompting players to report toxic behavior. Next, developers should explore their data and consider the salient features specific to their game.

Finally, while simple natural language-processing techniques can be somewhat effective, recent advances in machine learning in conjunction with domain-specific knowledge might be leveraged to produce more robust systems. The valance score used in Blackburn and Kwak (2014) is, like many sentiment scores, derived in part from a *dictionary* of words; thus, many toxic words in gaming, e.g., "noob," remain unscored.

However, recurrent neural networks (Serra et al. 2017) have been shown effective in learning out-of-vocabulary (i.e., unknown) words in the context of hate speech. Further, text-based detection can be combined with domain-specific information to further increase effectiveness. Consider Fig. 2, which plots occurrences of bigrams used by toxic League of Legends players as a match progresses (Kwak and Blackburn 2014). MOBAs like League of Legends tend to have early-, mid-, and late-game phases, and certain phrases are associated with certain points in the match. Combining advanced natural language processing while taking domain-specific information into account (e.g., the relative state of a match) is likely to greatly enhance any automated detection system.

Cross-References

► Toxic Behaviors in Online Gaming

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Player Behavior

► Player Abusive Behavior Detection

Player Experience

► Dark Souls Through the Lens of Essential Experience

► Timed Automata for Video Games and Interaction

Player Experience, Design and Research

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Synonyms

Affective ludology; Game usability; Games user research; Playability

Definition

Player Experience (PX) is a part of Games User Research where player experiences are studied to develop better interactions with games (L. E. Nacke et al. 2009a). The domain is the science of measuring user experiences for interactive entertainment – digital games being the prime focus (L. Nacke 2009a). It is proposed as a successor of User experience (UX) in HCI (Wiemeyer et al. 2016).

Introduction

PX considers games as a special software (Wiemeyer et al. 2016) and analyzes the quality of interactions of players with it. The domain focuses on the psychological, physiological (L. Nacke 2009a; L. E. Nacke et al. 2009a; Cowley et al. 2014), cognitive (Abeele et al. 2016; Järvinen 2008), emotional (Järvinen 2008), aesthetic (Sharp and Thomas 2019), and affective (L. Nacke 2009b) aspects of player

interaction within the games (Wiemeyer et al. 2016; Järvinen 2008). The primary goal is to measure PX along these aspects, and each of these aspects encompass multiple concepts within it. For example, flow is a concept of a psychological state that a player experiences while playing a game. The concept is measured using specific dimensions using a questionnaire. Player experience is thus multidisciplinary. Despite acknowledgment of its multidisciplinarity, there has not been a sufficient explication of concepts within the umbrella of PX Research in a larger context.

This article lists the constituent concepts of Player Experience and explains their contribution in studying Player Experience within the context of game studies. To understand what player experiences are, it is necessary to establish connections with influential psychological and affective concepts. The section on "Concepts Related to Player Experiences" enumerates influential work on such concepts. It is followed by research in games literature to achieve desired player experience by operationalizing those concepts and problems of such approaches. This article highlights the position of fun in the domain of player experiences and game studies. It concludes with future directions for Player Experience research, with emphasis on design research as a potential contributor to the domain of player experience.

Concepts Related to Player Experience

Player Experience research exists on a spectrum, where on one end, player experiences are analyzed from psychological and physiological perspectives. Thereby, the interactions of a player within the games are studied. On the other end of the spectrum, player experiences are analyzed with respect to the design of games. Both ends of the spectrum are analytical; they analyze player experience for different purposes. The section describes concepts from domains such as psychology, aesthetics, theory of emotions, etc., which have been applied to games and players' experiences.

Engagement

Every game strives for player engagement. It is considered as an indicator of a gameplay experience. As conceptualized by Brockmeyer, Fox, and Curtiss, a player engages with gameplay via the game software (Brockmyer et al. 2009). Similarly, Whitton considers engagement as an individual's interaction with an activity at a specific time, this engagement is not an activity but an interaction (Whitton 2011). Since players interact with gameplay via the 'special' software and engagement is not an activity but an interaction with the activity, Engagement in the domain of player experience considers engagement of a player with the software and not the gameplay. This concept can be broadened to engagement through gameplays, with adequate research.

Brockmeyer conceptualizes engagement in relation to flow, immersion, presence, and psychological absorption (Brockmyer et al. 2009). Psychological absorption is an important dimension to their questionnaire (Brockmyer et al. 2009). Psychological absorption is different from the states of flow and immersion. While flow is an autotelic state where an individual loses the sense of consciousness, absorption creates an altered state of consciousness, where affect is not accessible to the consciousness. The psychological absorption feels like "highway hypnosis" where the driver can be in an altered state of consciousness yet "manoeuvring responsibilities continue to be executed" (Brockmyer et al. 2009).

Flow

The concept of flow has been extensively used in studying player experiences. Conceptualized by Csikszentmihalyi, flow is an autotelic state that an individual experiences while performing an intrinsically motivating task (Csikszentmihalyi 1985; Nakamura and Csikszentmihalyi 2014; Csikszentmihalyi et al. 1990; Sherry 2004). The state has been characterized by: Increased and focused attention on the current activity, merging of action and awareness, loss of reflective self-consciousness, sense of control over one's actions, distortion of time experience, and experience of the activity as intrinsically rewarding. Although players of a game experience a flow

state, bridging work to analyze flow within player states needs further research.

Flow has been mapped to games elements from the literature in the Gameflow Model (Sweetser and Wyeth 2005a, b). This model provides eight dimensions offered by a game that puts the player in a flow state: Concentration, Challenge, Player skills, Control, Clear Goals, Feedback, Immersion, Social interaction. However, the model does not suggest means to design for flow (Sweetser and Wyeth 2005b). The concept of Flow has also been adapted to different categories of purposeful games as well. Dual Flow Model applies the concept of Flow to exergames and provides criteria for making attractive and effective gameplay in exergames (Sinclair, Hingston, and Masek 2009). The ARCS model for gameful learning uses dimensions of flow to improve attention, provide relevant learning content, and imbibe confidence in learners (Keller 1987). Thus, providing satisfaction to the learning experience.

The concept of flow has also been compared with the concept of enjoyment in some domains; however, there is a difference between the two concepts. Considering games as a medium that provides flow, other properties of media like Presence also become contributing factors to the state of flow.

Presence

There are several definitions of Presence which contest or compliment each other. Hence, it is best to understand Presence in terms of its conceptualizations. Presence is conceptualized in Media studies in six different ways (Lombard and Ditton 2006). In a general sense, presence is considered as a property of a medium. In this sense, a telephone can provide a lesser presence than a video conference. Of the six conceptualizations, Presence as Immersion is widely explored in the literature of PX. Although other conceptualizations are applicable to PX, Presence as immersion and Presence as transportation are explored in this article.

Presence as immersion is manifested in two ways: perceptual immersion (submergence of perceptual senses of the interactant by the media, as it happens in a VR experience) and psychological immersion (submergence via engrossment and engagement, like reading a book). Presence transports the interactants of the medium to a different place. Lombard and Ditton conceptualize transportation through presence as "you are there" where the subject is sent to an event or the object, "it is here" where the object or event is brought to the subject, and "we are together" where there is a shared reality between two interactants. This conceptualization is called Presence as Transportation.

The conceptualizations of Presence are applicable to media in general and provide some explications to characterize Presence offered by the medium. Better presence in media is characterized in terms of form variables (form of the medium), content variables (content offered by the medium) and media user variables (usage of the medium by interactant). Considering games as interactive media, Ermi and Mayra propose an immersion model for video games according to which, immersion in the game can be challenge based, sensory based, and imagination based (Ermi and Mayra). Immersion is provided by the rules, story, space, and interface of the game. However, it does not describe the constituents or means of achieving immersion or how to design for player immersion.

In addition to the concepts constituting player experience, some concepts that are treated as rewards are also important. Players essentially play games for intangible rewards, such hedonic pleasures like enjoyment and fun. Such concepts are significant for player experience.

Enjoyment

Enjoyment is equated with flow in sports psychology (Kimiecik and Harris 1996). Sociologists also explain enjoyment as an optimal psychological state. They characterize enjoyment as a psychological process that creates a positive experience. Enjoyment differs from the flow state as enjoyment can be achieved from extrinsically motivated activities (Podilchak 1991a, b). However, enjoyment is achieved only when flow is achieved (Kimiecik and Harris 1996). In this way enjoyment can be a motivator to enter the flow state.

Enjoyment in leisure studies is explained as a self-referential state where an individual experiences positive affect (Podilchak 1991a, b). According to Kelly, enjoyment is not socially or emotionally interactive and is primarily self-referential (vide, (Podilchak 1991a)). When a person is enjoying herself she sees herself in leisure or play (self-referential). On the contrary, fun is interactional, social and other-referential (vide (Podilchak 1991b)).

Fun

A player reaps fun while and after playing a game. However, it is not considered as a part of player experience frameworks and is often overlooked. The generality and lay usage of the word 'fun' adds to the difficulty of studying it from a measurement viewpoint.

Several overarching theories describing fun have been developed. Falstein brings in the evolutionary viewpoints to study fun ("Gamasutra – Natural Funativity" 2019). The emphasize that fun is not a by-product, but has evolutionary roots. He classifies fun into three parts – Physical fun, Mental fun, and Social fun. Fun is given an evolutionary purpose through this viewpoint. Anyone who enjoys developing survival skills is having fun. In this sense, a physical activity that enhances our survival instincts is condensed into Physical fun. Examples like exploration activities, use of tools, hunting are still found in present-day video games. Through Social fun, members of primitive society put their efforts to look out for each other. These efforts are manifested in forms of gossip, social gatherings, and now in present-day video games in the form of clans and communications in Massively Multiplayer Online Games (MMOGs). To achieve Physical and Social fun, players manipulate patterns of entities around us. This is defined as Mental fun. In this way, fun helps in learning new skills that are essential for survival. Ralph Koster establishes a similar line of thought. A game becomes boring (or not fun), when it stops offering new learning experiences and feels repetitive (Koster 2013).

Bogost describes fun in novelty and proposes that it is achieved by the act of reframing reality (Bogost 2016). Fun lies in transforming a reality to another reality that is unforeseen, unexpected, and novel. Fun is in finding the unfamiliar in familiar circumstances (Bogost 2016). Fun in this sense is in the act of manipulation. It is associated with processes of exploring, evaluating and presenting it to others, hence other-referential. In this sense, fun is also necessarily social (Podilchak 1991a). Such general viewpoints offer initial guidance to understand fun, but to identify dimensions of fun as an experience obtained from a gameplay, a more specific viewpoint with games in focus is needed.

John Sharp and David Thomas consider fun as an experience – "Fun describes the experience of a person playfully engaging with a situation or object" (Sharp and Thomas 2019). They consider play as the process of obtaining such an experience and extend the study of player experiences to the medium that provides such an experience. They refer to the domain as aesthetics of games.

Broad concepts like flow, fun, engagement, et cetera offer only some guidance to analyze games. These concepts are operationalized and measured through diverse approaches.

Operationalizing Concepts of Player Experience

Larger concepts are operationalized using smaller measurable concepts. Such a process is domain specific. Flow has been operationalized via Gameflow model in games and ARCS model in the domain of learning. In addition to operationalizations mentioned in the previous section, some concepts do not use established psychological or affective theories, but they take the empirical approach to create newer frameworks of player experiences.

The aesthetic part of the MDA framework focuses on the specific concepts to create player experiences and provides a list of eight components offered by the game (Hunicke et al. 2004). Similarly, GameFlow applies the concept of flow to come up with specific concepts for games (Sweetser and Wyeth 2005a). Another set of specific concepts has been provided by questionnaire-based measurements of player

experience – Game Experience Questionnaire (GEQ) (Denisova et al. 2016; IJsselsteijn et al. 2013), Player Experience of Need Satisfaction (PENS) (Denisova et al. 2016; Deci and Ryan 2012), Playful experience questionnaire (PLEXQ) (Boberg et al. 2015). Player experiences are studied in specific contexts like learning (ARCS) (Keller 1987), exergames (Sinclair et al. 2009) that provide us with domain specific elements of player experiences. Table 1 provides a list of specific concepts of the listed frameworks.

These frameworks and models rely on the measured aspects of player experience – psychological and physiological. The dimensions of these questionnaires help in analyzing player experience through self-reporting and affective ludology provides guidance in measuring the psycho-physiological variables of players to gauge player experience (L. Nacke 2009a). But the effects are not attributed to the design of the game. For example, the concept of flow is viewing at player experiences, but it is too general and "too vague for a detailed analysis of the game" (Järvinen 2007, 2008) Flow is a state of the player and not of a game ("Rules of Play: Game Design Fundamentals – Katie Salen, Katie Salen Tekinbaş, Eric Zimmerman – Google Books" n.d.). Its derivatives like the GameFlow model also help in measuring player experiences, but do not guide in designing those experiences (Sweetser and Wyeth 2005b). A detailed analysis of player experiences should either answer questions like why a player accepts challenges voluntarily? or should identify which features of a game system offer a particular experience?

Player Experience, Design and Research, Table 1 List of specific concepts associated with measurement of player experiences

Framework	Specific concepts
MDA	Sensation, Fantasy, Narrative, Fellowship, Challenge, Discovery, Expression, and Submission
GameFlow	Concentration, Challenge, Player skills, Control, Clear Goals, Feedback, Immersion, Social interaction
Patterns of flow	Challenging task balanced with skills, Path to more challenges, Feedback from the environment
Questionnaire	**Questionnaire**
GEQ	Competence, Sensory and Imaginative immersion, Flow, Tension, Annoyance, Challenge, Negative Affect and Positive Affect
PENS / SDT Approach	Autonomy, Competence, Relatedness, Presence, Intuitive Control
PLEXQ	Captivation, Challenges, Competition, Completion, Control, Cruelty, Discovery, Exploration, Expression, Fellowship, Humor, Nurture, Relaxation, ensation, Subversion, Suffering, Thrill
Context specific frameworks	**Specific concepts**
ARCS player experience for games	Attention, Relevance, Confidence, Satisfaction
Dual Flow Model	Attractiveness, Effectiveness

There are two shortcomings of current player experience research: (1) The analytical approaches consider games as a black box or a software to interact with. These analytical frameworks are not linked to the areas of games design (PPAX author). The psychological, physiological, emotive, affective, and cognitive dimensions of player experiences are measured and evaluated, but the design drivers of these dimensions have not been identified (Järvinen 2008). In other words, the analysis does not guide in the design of the games. (2) Current PX research does not engage with the notion of fun, despite being the central purpose of games.

Player Experience Design

Design research is oriented toward "finding the ultimate particular". It binds the general to specific through a common language (William and Alexander 2017). Player Experience research focuses on analysis, measurement aspects of the game experiences, while Applied Ludology attempts to provide this common language between player experience research and games design (Järvinen 2008). Applied Ludology provides ways to embody psychological variables in

the game states, thus providing an applicable theory to design for specific player experiences. Still, the domain of Applied Ludology poses the question – What are some design drivers affecting the emotional states through game events?(Järvinen 2008) How are those states formed from a given rule set? This is where Player experience design ought to operate. In this sense, player experience design should focus on the specific designable game elements that create desired game events and thus design better game experiences.

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Player Modeling

► Game Player Modeling

Player Personas and Game Choice

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Synonyms

Gameplay preference categories; Player profiles; Player types; Player typologies

Definition

Player personas are representations of player profile types, based on identified patterns in gameplay type preferences, motivations to play, or player behavior data. Player personas are constructed to support player-centric game design and targeted marketing.

Introduction

Since the early 1980s, categorizing video game preferences has been a sustaining topic in game research and game design literature. However, during the past 10 years, both mobile and non-mobile marketplaces have saturated, and the need for developing advanced player typologies for targeted marketing has become even more striking.

Consequently, many game companies lean today toward player-centric game development, which requires knowledge of the intended player audience and tools for identifying their representative player types or *player personas*. Determining the target audience impacts game design and monetization models, but it requires also a deep understanding of players' preferences and motivations to play (Adams 2014, pp. 32, 134–135). A core task for player profiling models is to aid game companies to design games with better market fit and to give tools for the players for discovering games that suit best their personal needs and thus to support their *game choice*.

This chapter explores prominent ways to identify player personas based on players' gameplay type preferences. After introducing approaches on profiling players in player type research, the chapter demonstrates empirically the role of gameplay preferences in game choice while taking into account both motivation to play and preferences for gameplay challenges.

Overview: Research on Player Types

Player type models can be distinguished from each other by identifying their main research

question. Models which study player behavior ask *how the player plays a game* and what kind of *play style* players adopt or prefer. Motivations to play and other psychographic approaches such as adaptations of the uses and gratification paradigm examine *why the player plays games* in general. Recently, another approach has been introduced for studying *what kinds of games players prefer* to play. These latter models argue that players can be profiled based on their preferences in gameplay types which arguably predicts their *game choice* (Vahlo et al. 2017). The fourth and final main approach on player types aims to identify *what kind of gaming mode*, gaming mentality, or game intensity a player exemplifies – e.g., if she could be described as a casual player, a social player, a hardcore player, or a competitive player (see, e.g., Ip and Jacobs 2005; Stewart 2011; Kallio et al. 2011; Deterding 2013).

Furthermore, some approaches focus on investigating players' personality types by applying existing psychological theories of personality and combining that with, e.g., player behavior data (e.g., Lankveld et al. 2011; McMahon et al. 2012) or survey data (e.g., Teng 2008; Jeng and Teng 2008; Braun et al. 2016). These studies ask *what kind of personalities distinctive player types have*. In a sense, these models are second-order approaches on player types since they investigate the correlations between two existing branches of research: personality types and player types.

Player typologies can be approached from the perspective of segmentation and marketing theory (Hamari and Tuunanen 2014) or by making a distinction between player profiling and player modeling. *Player modeling* designates scrutinizing patterns of dynamic interaction in ongoing gameplay. *Player profiling* is based on analyzing information that cannot be reduced to gameplay but which refers instead to players' sustaining game preferences, motivations, and, e.g., cultural background. (Yannakakis et al. 2013; Cowley and Charles 2016) Player modeling is congenial with player behavior studies, whereas player profiling points toward models of gameplay type preference and motivations to play. The concept of "persona" has been utilized in player modeling studies in the task of recognizing consistent patterns of archetypical play styles (Tychsen and Canossa 2008; see Cooper 2007).

The most well-known behavioral player type model was fashioned by Richard Bartle (1996, 2003). Bartle's model was based on analyzing several hundred bulletin board postings by MUD (multiuser dungeon) users and classifying their preferred playing styles into four player types of *achievers*, *explorers*, *socializers*, and *killers*. Regardless of the fact that the model was based on players' preferred play styles in MUDs and it was not intended as a general model, it has been widely used in game development for two decades.

Player behavior models (e.g., Bartle 1996, 2003; Drachen et al. 2009; Mulligan and Patrovsky 2003; Tseng 2010; Stewart 2011; Bean and Groth-Marnat 2016) are useful for understanding how players play the game they have already chosen to play and what kinds of temporary or more constant play styles can be identified by behavioral profiling (Pirker et al. 2016). Thus player behavior models offer data for improving retention and monetization of a given game. However, it is difficult to make general conclusions of player personas or their game choices beyond the preselected game of which data (e.g., telemetric data, game logs) is being analyzed.

Bartle's (1996, 2003) model was also used as the starting point for a major investigation on motivations to play massively multiplayer online role-playing games (MMORPGs) by Nick Yee (2006). By conducting principal component factor analyses ($N = 3000$) on inventory of 39 items that were generated based on Bartle's (1996) four player types, Yee was able to identify ten components that further loaded on three overarching latent dimensions of *achievement*, *social interaction*, and *immersion*. Later the model was validated by conducting a confirmatory factor analysis with cross-cultural data (Yee et al. 2012).

Motivations to play models aim to flesh out the reasons why people play games in general or, e.g., online games or mobile games in particular. These models, as well as player *personality type* approaches, are often based on existing psychological theories including Myers–Briggs Type

Player Personas and Game Choice, Table 1 Four primary approaches of video game player type research

Model	Core research question	References	Model emphasis
Gaming intensity	*What* is the preferred gaming mode?	Kallio et al. (2011)	Player profiling
Motivations to play	*Why* do we play games?	Yee (2006)	Player profiling
Gameplay type preferences	*Which* games we choose to play?	Vahlo et al. (2017)	Player profiling/ player modeling
Player behavior	*How* we choose to play a game?	Bartle (1996)	Player modeling

Indicator (e.g., Bateman et al. 2011), Big Five (e.g., McMahon et al. 2012), HEXACO model (e.g., Worth and Book 2015), the uses and gratification paradigm (e.g., Sherry et al. 2006), or Self-Determination Theory (e.g., Ryan et al. 2006; Przybylski et al. 2010). However, psychological theories are developed to deal with general traits of human psychology – not with situational behavior such as gaming. Motivations to play models may not provide much information of what kind of games people prefer to play or what play styles they are likely to adopt, and thus these models can be difficult to utilize in game development.

Both player behavior models and motivations to play models can be argued to be limited in the objectives of profiling players' gameplay type preferences and predicting players' game choice. Recently, two models have been developed for this purpose (Vahlo et al. 2017; Tondello et al. 2017). Vahlo et al. (2017) presented an approach based on identifying recurrent game dynamics, i.e., patterns of interrelated game mechanics as they emerge in ongoing gameplay, of contemporary video games ($N = 700$). After identifying 33 core game dynamics types, they fashioned a survey for 1,718 participants from Finland and Denmark (age 18–70) in which the participants' preferences in each of the 33 game dynamics were enquired. An exploratory factor analysis revealed five factors of game dynamics preferences, namely, *assault*, *manage*, *journey*, *coordinate*, and *care*. The authors conducted a cluster analysis based on respondents' factor scores, i.e., like/dislike of the five game dynamics factors, and identified a total of seven player types or personas of *the mercenary*, *the companion*, *the adventurer*, *the commander*, *the patterner*, *the explorer*, and *the daredevil* (Table 1).

Vahlo et al. (2017) and Tondello et al. (2017) both argue that focusing on game dynamics or gameplay activity types fills a gap in current player type research since this approach makes it possible to combine the elements of games with players' preference profiles. Arguably, this posits gameplay type preferences as a tool for both profiling players into player personas and predicting their game choice. The gameplay type approach is congenial with media choice theory and especially with structuration theoretical models which argue that dynamical and structural characteristics of game media constitute an important factor in identifying media choice and, consequently, game choice (Webster 2009).

Empirical Demonstration: Gameplay Type Preferences and Game Choice

Gameplay can be defined as the interaction between the challenges the player faces and as the actions the player is allowed to take to overcome the challenges in a fictional setting (Adams 2014, p. 9). Gameplay of a game does not, however, consist only of types of gameplay challenges and fictionality. The player tries to overcome the challenges in gameplay activities, i.e., game dynamics, such as exploring the gameworld, managing cities, shooting enemies, piloting vehicles, or taking care of farms (see Vahlo et al. 2017; Vahlo 2017). It can be offered, therefore, that gameplay type preferences can be broken down into three dimensions of challenges, activities, and fictionality (e.g., narrative, theme, and

aesthetics) and that these three dimensions can be appropriated as a basis for constructing player personas to predict game choice. Following Adams (2014), challenges and activities are considered here to form the core of player–game interaction.

In gameplay, the player may come across with, e.g., tactical challenges, challenge pattern recognition, logical challenges, challenges of memory and knowledge, or challenges of physical coordination (Adams 2014). The challenges are dealt with by engaging in distinctive types of gameplay activities. For instance, a player may have to coordinate her physical movement in activities of dancing, sneaking, or jumping on platforms. It is plausible also to assume that a person who decides to play has some kind of *motivationa*l driver to do so. Indeed, the question of how distinctive forms of goal-directed activities in gameplay relate with psychological need satisfaction has also been studied in prior game research (see e.g., Bostan 2009).

This section presents an empirical demonstration, which was designed to investigate how being motivated to play, enjoying gameplay challenge types, and appreciating gameplay activity types predict game choice. A total of 3551 survey respondents were obtained in 2016–2017 from Canada ($N = 1364$), Japan ($N = 1270$), and Finland ($N = 917$) to construct representative samples from the three countries. The surveys were made in cooperation with a market research company by using a web-based tool. The age of the participants ranged from 18 to 60 years. In the beginning of these surveys, the respondents were enquired to report on a Likert-5 scale how interested they were in digital games (1 = not at all, 5 = very interested). If a respondent reported to have no interest in video games at all, he or she was then instructed to quit the survey.

The surveys included a 25-item motivations to play inventory (Likert-5, 1 = completely unimportant, 5 = very important), 9-item gameplay challenge preference inventory (Likert-5, 1 = very unpleasant, 5 = very pleasant), and a 52-item gameplay activity preference inventory (Likert-5, 1 = very unpleasant, 5 = very pleasant), where the latter was based on the model by Vahlo et al. (2017). Respondents' habits of playing digital games of a total of 17 distinctive genres were enquired by asking how much they played games of each genre (Likert-5, 1 = not at all, 5 = very much).

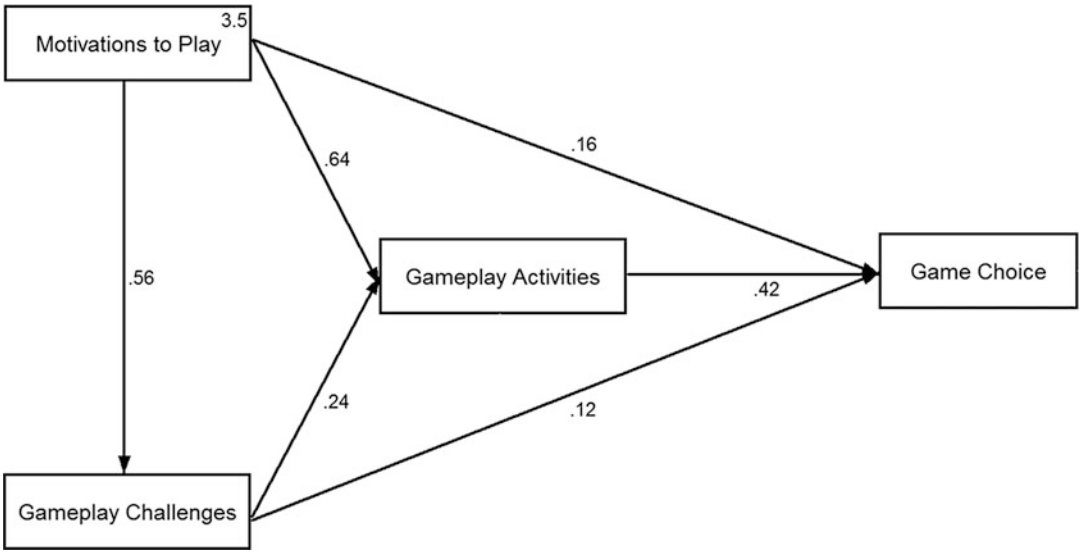
A structural equation model (SEM, Stata 14.2) was constructed for investigating how being motivated to play, enjoying gameplay challenge types, and appreciating gameplay activity types predicted respondents' habits of playing games of the variety of genres. The measurement model is presented in Fig. 1.

The indirect, direct, and total effects for the model (Fig. 1) were estimated by using maximum likelihood method. In the data of 3551 respondents, being motivated to play was the main predictor of playing games of all genres (0.55). However, the effect of being motivated on the game choice was largely *indirect* (0.39). Gameplay type appreciation had the second largest total effect on playing games of all genres (0.42), and it had clearly the strongest *direct effect* on playing games of varied genres. Gameplay challenge preference had only weak (0.22) total effect on the game choice, and both its indirect (0.10) and direct (0.12) effects can be considered very weak.

Based on these results, it can be offered that motivations to play, gameplay challenge preference, and gameplay type appreciation are all significant factors in predicting game choice. Although being motivated has the largest total effect on playing games of varied genres, gameplay appreciation has much more relevant direct effect on game choice. Since motivation has only weak *direct* effect on game choice, it is plausible to suggest that constructing player personas on game choice can be primarily based on players' gameplay type appreciation and secondarily on their gameplay challenge preferences.

Conclusion and Discussion

This chapter provided an overview of prominent approaches to player type research and player



Player Personas and Game Choice, Fig. 1 A game choice prediction model reporting standardized effects of motivation, challenge preference, and gameplay type appreciation on playing video game genres ($N = 3551$). All reported effects are significant on the level of $p < 0.001$

profiling. It pinpointed qualitative differences between the four approaches of motivations to play, player behavior, gaming intensity, and gameplay type preferences. All of these approaches can be used to construct personas, i.e., representative players, for the developer and marketing.

The chapter demonstrated empirically a structural model predicting game choice based on motivations to play, challenges, and gameplay activities. Based on the empirical demonstration, one can argue that for business purposes player personas based on gameplay activity preferences are the most promising and yet underutilized at the moment.

Demonstration showed that one approach is not adequate. All the factors have an impact on game choice, and therefore businesses should seek to have wider understanding of the whole phenomenon. More data should be collected to understand better media consumption and purchase behavior. One solution for that task could be developing AI-based engine for generating personalized game recommendations for distinctive player segments and simultaneously collecting data concerning persona responses to different marketing methods.

Cross-References

- Game Player Modeling
- Game Thinking X Game Design Thinking
- Psychology in Game Design
- Videogame Engagement: Psychological Frameworks

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Player Profiles

▶ Player Personas and Game Choice

Player Types

▶ Player Personas and Game Choice

Player Typologies

► Player Personas and Game Choice

Player-Avatar Link: Interdisciplinary Embodiment Perspectives

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Synonyms

Bodily presence in digital games; Embodiment in digital games; Player-avatar relation

Definitions

Player-avatar link: experience of embodiment by the player, caused by the extension of the player's perception and agency through the avatar into the digital game world.

Introduction

In digital games research, the concept of the avatar is a much discussed topic. Many works have been dedicated to understanding every aspect of this phenomenon, ranging from the origin of the term all the way to its functioning as a game component (see Juul and Klevjer 2016 for a brief overview of key discussions). Once the aspect of the player is addressed, one of the most intriguing issues become the link between the player and the avatar they control. Why is it, for example, that players become distressed when they see their avatar in danger? And why do they refer to it as "I"? While it is widely acknowledged that some type of link indeed exists, there is still much disagreement on what the nature of this link actually is. This entry discusses the different embodiment perspectives of the player-avatar link. Specifically, we first examine phenomenological accounts of player embodiment in games from a Humanities background, and then investigate the sense of embodiment in virtual media from a Natural Sciences background.

Terminology

A few concise definitions are provided as a starting point for the main discussion. These definitions are simplified versions of what they may represent within different disciplines.

Avatar – The object over which the player can assert control.
Character – The figure that exists in the meaningful game world, including any form of backstory and personality.
Embodiment – The process of adjusting one's internal body representation to the current circumstances.
Player embodiment – The experience that the avatar has changed the internal body representation and phenomenal body of the player.
Presence – The experience of being present to something.
Spatial presence – The experience of being present in a certain environment.
Immersion – The technological quality with respect to sensorial information.

In the following, the term "game figure" is used to refer to either avatar and/or character, when it is not specified by the author(s) of the cited article.

Perspectives Within the Humanities

In the Humanities there are several authors who acknowledge that the player-avatar link is exactly embodiment, in the form of extension of the player's body. In a number of his works, Wilhelmsson has argued that many aspects of a game experience are consequences of a Game Ego manifestation (Wilhelmsson 2001, 2006, 2008).

The Game Ego is a bodily based function that enacts a point of being within the game environment through a tactile motor/kinesthetic link. This means that the player's sensory system is extended to the game environment, and the Game Ego becomes another body and/or an extension of the body. The consequences include identifying with the manifestation and more generally allowing the player to experience the game's narrative elements, and as a result evoking emotional responses and the experience of presence. Klevjer states that there is a paradoxical prosthetic relationship between player and avatar (Klevjer 2006, 2012). By applying Merleau-Ponty's philosophy on the body's duality (Merleau-Ponty 1945), it is argued that video games allow the player to relocate their intention for actions (as a subject) into screen space, while at the same time a proxy (as an object) exists in the game. Crick also draws upon Merleau-Ponty's reasoning to explain how the game can be perceived as another physical world during play (Crick 2010). That is, the player exists in two worlds and operates both on and in the game. It is emphasized that the video game experience must be of embodied perception, since we still require our body (and the combination of all senses) to perceive it, and it in turn affects our bodily state. The controller used by the player allows agency in the game world and can become an extension of our body through habit; the avatar's movement is incorporated within the player's body schema and becomes an extension of the bodily basis of consciousness. Lastly, Vella argues that, indeed, the player may embody the avatar and achieve a subject position in the game world, but as a character the game figure still has an autonomous identity that can be acted out (Vella 2013). Therefore, the act of avatar-play constitutes the enactment (or performance) of a character.

These works so far demonstrate an emphasis toward the roles of perception and cognition in embodiment: their combined impact on our experience of the real world is considered in the experience of game worlds. Farrow and Iacovides claim that exactly such reasoning is just one step too far (Farrow and Iacovides 2014) and describe three inconsistencies with respect to human embodiment aspects laid out by Merleau-Ponty. Firstly, on a physical level bodies within game worlds cannot conform to real world duality (e.g., tactile and pain), and we do not relate to bodies in virtual worlds in the same way that we do in the real world. Secondly, on an intentional level a player experiences the game as convincing when there is a sense of nonmediation, which is something only "invisible" game control systems can achieve. Lastly, on a worldliness level it is possible that game worlds only become meaningful through play with other humans. Together, this leads to a limit to the degree of digital embodiment.

There are also authors that explain that embodiment in games is not "simply" a process of perception. For example, Newman has argued that "video games are not interactive, or even ergodic," since they do not consist of continuous play and even have integral parts that are nonergodic (Newman 2002). Here, ergodicity refers to the definition by Aarseth: a user must use (active) effort in order to experience the medium (Aarseth 1997). Moreover, there is a level of ergodicity in noncontrolling players (active spectators), which indicates that feelings of immersion, engagement, and being-in-the-game are separated from an interface-level control loop. During play, the degree to which the player embodies the game figure is not dependent on representation, since it is merely seen as a set of capabilities: it is equipment to be used by the player.

A last group of authors agree that the player-avatar link takes on more forms than just embodiment and that this is very related to different types of play. Linderoth demonstrated how children frame the game figures during certain moments of gameplay, which leads to three different functions of game figures (Linderoth 2005): they can become roles for socio-dramatic interaction, tools as extensions of the player agency, and props for self-presentation in the presence of others. Similarly, Bayliss argues there are three positions of game figure play: playing through (the avatar is equipment), playing as (sometimes character, sometimes avatar), and playing with the game figure (play with the game rather than play the game) (Bayliss 2007). The game figure embodies the intentions of the player as their avatar, and its limitations with respect to functionality

simultaneously constitute it as an embodied character. It is highlighted that any sense of being-in-the-game-world relies on attitude of the player with respect to the three positions of play, and not the video game itself or the technological platform. Lastly, Banks found that players' motivation and attitude toward play went hand in hand with the social role the game figure fulfilled in the relation with the player (Banks 2015). From unsocial to social, the relations were game figure as object, as me, as symbiote, and as social other.

To summarize, there is a substantial group of authors that argues for embodiment of the player as a result of a perceptual link: the player's body is extended into the game through the avatar. However, others argue that real world embodiment assumptions cannot simply be translated to assumptions for the game world and that the function of the game figure depends on the type of gameplay, which in turn depends on the player's attitude toward the game.

Perspectives Within the Natural Sciences

In the Natural Sciences, there is little attention to the player-avatar link in games specifically; however, there are many works that discuss how the body schema can be changed by virtual bodies in, for example, virtual reality (VR). This corpus is a result of empirical studies in cognitive neuroscience on the more general experience of being connected to a body. Although there are many concepts that are part of this experience, there are three in particular that have gained a great deal of attention, that together form the sense of embodiment: body ownership (the sensation of owning a body), agency (the sensation of controlling a body), and self-location (the sensation that the locations of you and your body coincide in space) (Kilteni et al. 2012a; Longo et al. 2008). Here, spatial presence differs from self-location since the former concerns the relation between the self and the body, and the latter the self and the environment. A classic experiment to assess ownership over a limb is the rubber hand illusion (Botvinick and Cohen 1998). In this experiment, the rubber hand is stroked either synchronously or asynchronously with the real hand, which is out of sight. Synchronous feedback evokes a sense of ownership over the rubber hand, while asynchronous feedback diminishes it. With similar setups for not just limbs, but also entire bodies (i.e., the body transfer illusion), various studies have assessed the importance of seemingly relevant factors to the illusion, such as synchronous visual–tactile and visual–motor feedback (Tsakiris et al. 2006), viewing perspective (Petkova and Ehrsson 2008) and congruent body alignment and connectivity (Perez-Marcos et al. 2012). It has also become apparent what the roles of agency and self-location are in this regard (Kalckert and Ehrsson 2012; Maselli and Slater 2014; Tsakiris et al. 2006).

Using VR it became possible to inspect real-world factors that could not, or with much difficulty, be studied otherwise. Lugrin et al. examined the body transfer illusion during a full-body touch-the-target task in VR, where ownership over humanoid, robot, and block avatars were compared (Lugrin et al. 2015). They found that there was no difference in ownership levels between the different avatars (the actual levels are not provided); however, the humanoid avatar caused the participants to experience having two bodies to a higher degree than the other non-humanoid avatars. The authors believe that this effect was related to the so-called uncanny valley effect. Besides full-body illusions, the extension and addition of body parts has also been examined. For example, Kilteni et al. examined how the degree of ownership over a virtual arm depended on elongation of the arm and found that with visual–tactile feedback the breaking point was four times arm's length (Kilteni et al. 2012b). Regarding supernumerary limbs, Steptoe et al. showed that participants could experience ownership and agency over a humanoid avatar with a long tail, while also performing better in a full body touch-the-target task when the tail could be controlled by hip movement than when it moved at random (Steptoe et al. 2013). In a similar study, Stevenson Won et al. compared performance in an armbased touch-the-target task between a humanoid avatar and one with an extra arm protruding from the chest, which could be controlled by wrist rotations (Stevenson Won et al. 2015). For targets outside of the normal arm's reach, but in reach of

the additional arm, participants performed significantly better with the extended body than with the normal body. Interestingly, the measured levels of presence were low overall and did not differ between conditions. The authors explain that the low results could have occurred because participants were so involved with controlling the avatar in order to complete the task, making them less aware of the virtual surroundings. This is in contrast to many works in Natural Sciences that agree that there is in fact a positive relation between presence and task performance (an elaborate discussion can be found in Nash et al. 2000).

Although measuring embodiment in games directly (i.e., through ownership, agency, and self-location) is uncommon, there have been many works that measure presence and/or immersion in games for a variety of purposes. For example, in a series of studies, Weibel and Wissmath studied possible influences and effect of spatial presence and flow in a variety of games using both factor analysis and path analysis on questionnaire results (Weibel and Wissmath 2011). Firstly, they found that spatial presence and flow are separate constructs and that flow in turn consists of two subcomponents: absorption into the experience and smoothness of the experience. Secondly, they found that a participant's motivation generally influences flow, whereas a participant's immersive tendencies generally influence presence. Lastly, flow directly influenced enjoyment and performance of each game, whereas presence only did this indirectly through flow.

Besides subjective qualities of gameplay, objective qualities have also been examined. For example, Hou et al. studied players' immersive tendencies as a precondition of presence experience, and screen size as a media form variable (Hou et al. 2012). By analysis of questionnaire results they found that a larger screen had a positive effect on game figure evaluation, player mood, and both spatial and self-presence (i.e., when a player experiences that the avatar is him-/herself), but no difference in enjoyment. Also, immersive tendencies moderated the effect of screen size on presence, but not of the other game evaluation aspects. In particular, enjoyment was not affected, in contrast to the study by Weibel and Wissmath.

To summarize, although there is little research on the player-avatar link itself, there is an immense corpus of literature regarding the general experience of being connected to a body in reality and VR that prominently argue from a perception background: multimodal feedback can cause participant's to experience other (virtual) bodies as their own. There have also been studies that empirically show that a player's immersive tendencies are an important determining factor of the experience of spatial presence in games.

Body and Environment

Although the different disciplines study the same problem very differently, there are a few interesting similarities between the two, specifically regarding their interpretation of the problem. For example, both disciplines agree that during gameplay the player's internal body representation changes. In Humanities, some authors draw upon the phenomenology of (natural) perception and argue that a part of the player must be represented in the game. In Natural Sciences, the reasoning is that if extra bodies (or body parts) are presented correctly, then they can be accepted by the player as belonging to them. Both sides argue for an extension of the player's body, and many results support this claim: players frequently refer to the avatar as "I," react emotionally and physiologically to avatar events as if it is their real body (Armel and Ramachandran 2003), while still experiencing ownership over their actual real bodies (Guterstam et al. 2011).

Another similarity is the important role of the experience of the game environment, in particular what the determining factor is of this experience. In computer science, it was until recently quite acceptable to regard presence as a consequence of a system's immersive and interactive capacities (and of nothing else). This is often a crude operationalization of Steuer's model on presence in VR (Steuer 1992); the statement concerning varying individual experiences of presence due to, for example, differences in the content is frequently ignored. Currently, a progressively growing number of studies are demonstrating the importance of the player's immersive tendencies

to the experience of the environment. In game studies, system-versus-narrative discussions are nothing new: Is the experience of spatial presence (or being-in-the-game-world) a result of the vividness and interactivity of the system, or is this a result of the environment becoming meaningful through narrative? There are numerous authors that are inclined toward the latter (Bayliss 2007; Farrow and Iacovides 2014), although undoubtedly the answer is partially both. A possible reason for the exclusion of this view in computer science is one of pragmatic nature: there is not yet an existing measure for "the degree of narrative." This is absolutely logical when looking at the complexity of the matter; the experience of narrative can differ per person, per experience of gameplay, time of day, and so on, but that does not mean it is nonexistent.

For research in both disciplines, the experiences of self, body, and environment often go hand in hand. In many cases, it seems to (roughly) come down to two aspects: the role of mediation and the role of immersive tendencies. That is, the only way a person could experience a mediated situation as real is if the input is *realistic* (or convincing) enough, and if they allow themselves to *pretend* the experience is not mediated. It is not apparent what the interdependence is between these two aspects, nor whether they are of equal importance: acceptance in the second aspect allows experience of the first on the one hand, but it may very well be that if the first occurs perfectly then the second happens automatically (as suggested in Wilhelmsson 2008).

Conclusion

This entry has provided an interdisciplinary discussion of the player-avatar link. For Humanities we see that there is no consensus on the importance of perception over player attitude and narrative. In Natural Sciences, the experience of changing the body schema through perception is prominent; however, there is recently also noticeable focus on personal characteristics that might underlie the experience in the first place. Both disciplines are inclined to argue about the experiences of both body and environment and end up at the same important question: What are the roles of mediation and immersive tendencies in these experiences? In this sense, while the initial analysis from both disciplines seemed contradictory, one could say that for this particular problem the focus in both disciplines is converging, creating a interesting future research opportunity for interdisciplinary research in this area.

Cross-References

▶ Cognitive Psychology Applied to User Experience in Video Games

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Player-Avatar Relation

► Player-Avatar Link: Interdisciplinary Embodiment Perspectives

Playful Design

► Gamification

Playground

► Games and the Magic Circle

Playing

► Online Gaming Industry Evolution, Monetization, and Prospects

Plugin System

► Decoupling Game Tool GUIs from Core Editing Operations

Plug-in-Based Asset Compiler Architecture

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Synonyms

Build toolchain; Data baking; Data compiler; Data cooking; Data processor

Definition

A plug-in-based asset compiling solution for game development where each plug-in handles a data file format and outputs an optimized form for a specific hardware/software platform.

From the beginning of the game creation process to the end, development revolves around two main subjects: code and data (game art and other type of assets). In the past, data was formatted specifically for the one platform the game was about to run on. Now we have to format the same data for many different platforms. In order to satisfy this new requirement, we need access to source assets that can be compiled into a variety of targets. More work has to be done, since special care has to be taken for each format.

However, there are ways to reduce the pain involved in this more complex pipeline. To make this process as streamlined as possible, a plug-in-based asset compiler that can load converter plug-ins for the given asset types, is proposed. The plug-in-based nature of the compiler can also help developers create their own plug-ins for any other special asset types they need. In this entry, I describe how to set up and code such a compiler using the example of a texture converter/compiler plug-in. The platform we are going to use is Windows and the language is C++, with few modifications regarding the OS specifics, the code should work on other environments or even adapted to other languages.

Design

The underlying plug-in loading system can be a "traditional" dynamic link library (DLL) loading and querying for the proper interfaces. We will be using the Windows dynamic link library API, but the code is almost the same for other operating systems. The DLL can export a special function that will return an instance of the converter interface (see Listing 1). The same goes for other platforms (OS/X, Linux), using their specific dynamic link library API implementations.

Listing 1. Creating the asset converter instance using the exported DLL function

```
DLL_EXPORT AssetConverter*
createAssetConverter();
```

The interface of the asset converter would look like Listing 2.

Listing 2. The asset converter interface

```
class AssetConverter
{
public:
enum EType
{
eType_Unknown = 0,
eType_Compiler = 0>>1,
eType_Importer = 1>>1,
eType_ImporterCompiler
= (eType_Compiler | eType_Importer)
};

AssetConverter(){}
virtual ~AssetConverter(){};
virtual bool convert(const char*
pSrcFilename, const char* pDestPath,
const Args& rArgs) = 0; // Args class
is a command line argument parser, not
shown here. Basically holds a list of
arguments and their values
virtual const char* supportedExtensions
() const = 0;
virtual EType type() const = 0;
};
```

The asset converter has a type that represents what the converter does with the given input file:

compiles or converts. We make this distinction between compilers and converters because we would like to use compilers to compile data from our intermediate format to the final platform-optimized format and converters to convert from third party formats to our intermediate format. An example compiler would be: cube.json (the intermediate format) to cube.mesh (final optimized format) or an example converter: cube.fbx to cube.json.

We can also have a compiler and a converter in one implementation (flag eType_Importer-Compiler) that can handle third party and intermediate formats (for example, a TextureConverter that converts third party JPG/PNGs and compiles to a custom format like.TEX).

The convert method is the one called by the asset compiler executable when the given command line arguments are passed to it and they match the file extensions returned by the supportedExtensions() method. This function should return something like a file mask such as *.jpg, *.tga, *.png, or *.texture, so even a simple substring matching test can select the right converter(s).

The command line arguments are shared for all the converters; each one can pick up its own arguments and their values.

By convention, the converters will be called first on the given assets, and after that we will call the compilers. Since we (probably) generated/converted assets from the previous step, now we can compile those intermediate formats into final binary optimized ones for specific platforms.

The main asset compiler executable will load all plug-in DLLs from either a specific folder or the same folder as the executable. We can use any kind of plug-in loading scheme. For example, we can have those DLLs with their extensions named. plugin,.converter, etc. In this way, we dynamically load only the eligible ones, skipping the unsupported/unknown DLLs.

Once a plug-in is loaded, we retrieve the address of the DLL exported createAssetConverter() function and instantiate the converter. Then, with all plug-ins loaded, we match each input asset filename with the return string of the supportedExtensions() of each converter. If the match is true, then we call the converter to take care of that file type. After that we can continue to pass the filename to be handled by other matching converters, or we could come up with a stop boolean return value so the file will be handled only once by a single converter and not by further matching converters if the return value is false. Even further, we could have some sort of dependency tree, when converters would be called after others have finished converting assets.

Obviously, another thing that speeds up the compilation/conversion process is multithreading. In a first phase, we can schedule groups of files to be converted on separate threads. Then, when we convert a few files, the converters could spawn several threads to take care of a single asset. We must be sure, however, that the available cores are used/spread evenly, whether on a CPU or GPU.

Multithreading asset compilation can be a little tricky when dependencies are involved, so for this process to be safe, and to avoid problems arising from two threads concurrently modifying the same resource, we should build a dependency tree and put each main branch and its subbranches and/or leaves on their own thread. Various methods for thread synchronization can be used, like mutexes, semaphores, each operating system having its own API for that.

The main compiler class would look like Listing 3.

Listing 3. The asset compiler class

```
class AssetCompiler
{
public:
AssetCompiler();
virtual ~AssetCompiler();

bool compile(const Args& rArgs);
void compileFolder(
AssetConverter::EType aConverterType,
const char* pMask,
const char* pExcludeMask,
const char* pCompileFolder,
const char* pDestFolder);
protected:
vector<AssetCompilerWorker>
m_workerThreads;
.....................
};
```

The main asset compiler class has the compile(. . .) method (synchronous call; it will wait until every asset compile thread finishes), which will take the actual command line arguments. The compileFolder(. . .) method (asynchronous call; it will just start the threads) will process a given folder for a specific converter type, with a filename mask, an excluding mask, the actual compile folder, and destination folder for the output files. The class also has some worker threads for multithreaded processing of the input assets.

Example

We can show, for example, a texture converter/compiler plug-in. The code could look like Listing 4.

Listing 4. The texture converter and compiler

```
class TextureConverter : public
AssetConverter
{
public:
TextureConverter();
~TextureConverter();

bool convert(const char*
pSrcFilename, const char*
pDestPath, const Args& rArgs);
const char* supportedExtensions()
const
{
return "*.jpg *.png *.psd *.tex";
}
EType type() const
{
return eType_ImporterCompiler;
}
};
```

The texture converter plug-in class will return all supported file extensions and its type, so the main compiler class will select it when appropriate.

Inside the convert method, the code will check the input filename and dispatch the logic to the specific image format handler.

This class can reside in a DLL, which contains a single converter, but one can also have as many converter classes in a DLL as it is needed. In that case, the query function will just have to change to support multiple classes. See Listing 5.

Listing 5. A plug-in with multiple converter classes inside a single DLL

```
// this class must be implemented by
the plug-ins
class AssetCompilerPlugin
{
virtual int getClassCount() = 0;
virtual AssetConverter*
newClassInstance(int aIndex) = 0;
}
DLL_EXPORT AssetCompilerPlugin*
createPluginInstance();
```

The exported createPluginInstance() will create the plug-in's class instance, which will take care of instantiating converter classes.

Other converter plug-in examples include an FBX converter, mesh compiler, prefab compiler, shader compiler, MP3/OGG/WAV converter, level compiler, etc. The plug-in system can be developed further with class descriptors, such that information can be retrieved about the converter classes without having to instantiate them unless they are needed.

Conclusion

Making the asset compiler modularized can yield huge benefits: shorter development time, the ability to extend and debug the tool, and happy third party developers, who will use the tools since they can implement new converters/compilers for their custom data file formats.

Keep in mind optimizations like multithreading; dependency trees; CUDA/GPGPU operations to speed things; a CRC-based last-modified file info database so we can skip assets that have not changed; and even safely running many compiler executables on the same data folders.

The solution can be implemented in various ways. The converter ecosystem can be detailed as needed so it will fit perfectly into the game engine's pipeline.

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Point and Click Game

► Five Nights at Freddy's, a Point and Click Horror Game

Poisson-Disk Sampling

► Poisson-Disk Sampling: Theory and Applications

Poisson-Disk Sampling: Theory and Applications

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Synonyms

Blue noise sampling; Poisson-disk sampling

Definitions

The Poisson-disk sampling is a sampling strategy or process that will ensure each sample to be independent to each other with a certain random distribution, while keep a certain minimum distance r from each other.

Introduction

Sampling has a crucial importance in computer graphics theory and applications. The digital system of a computer will need effective and high-quality sampling algorithms to convert continuous-time signals to discrete-time signals while preserving as many details as possible. A good sampling algorithm will dramatically increase the efficiency and quality of many computer graphics applications such as texturing, object placements, remeshing, and rendering. Figure 1 shows two different sampling patterns.

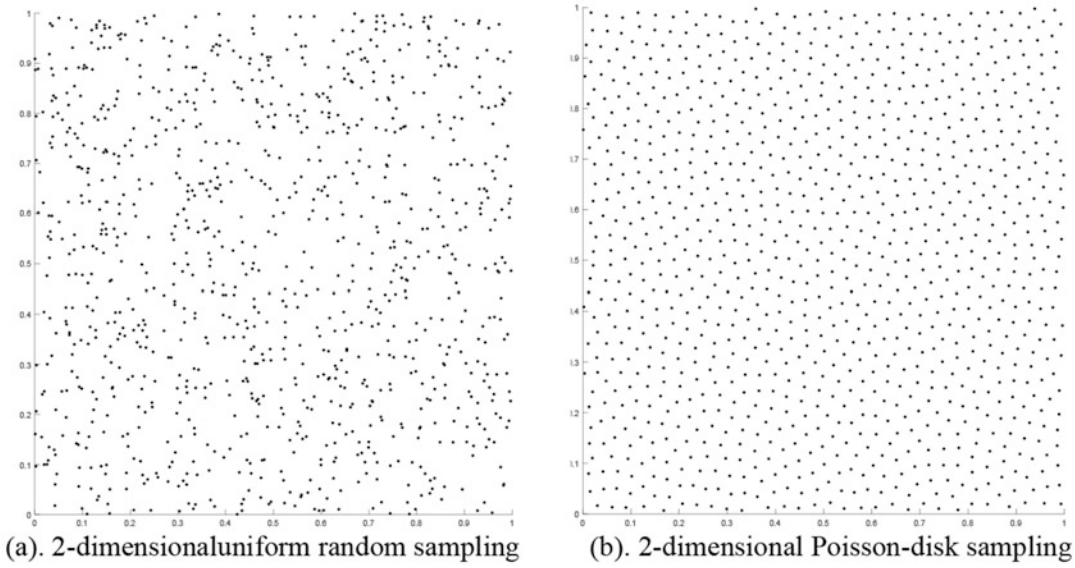
The problem with uniform random sampling in the 2D spatial domain is that it will introduce variance that can cause high-frequency noise in some applications. A uniform random sampling will leave gaps and clusters in the sample domain. In the gap area, underlying information cannot be efficiently evaluated, while in the cluster area redundant evaluation will harm the efficiency of the application.

To solve such a problem, we need to introduce samples that have both unbiased randomness in the distribution, while scattering in the sampling domain with low variance and discrepancy. **Poisson-disk sampling** is the most popular sampling strategy that can generate such evenly distributed samples with unbiased randomness. A broader concept of such an ideal sampling pattern that has unbiased randomness with evenly scattered samples is called **blue noise sampling**. Figure 2 will show problems of uniform sampling and how the Poisson-disk sampling pattern can help to solve such problems.

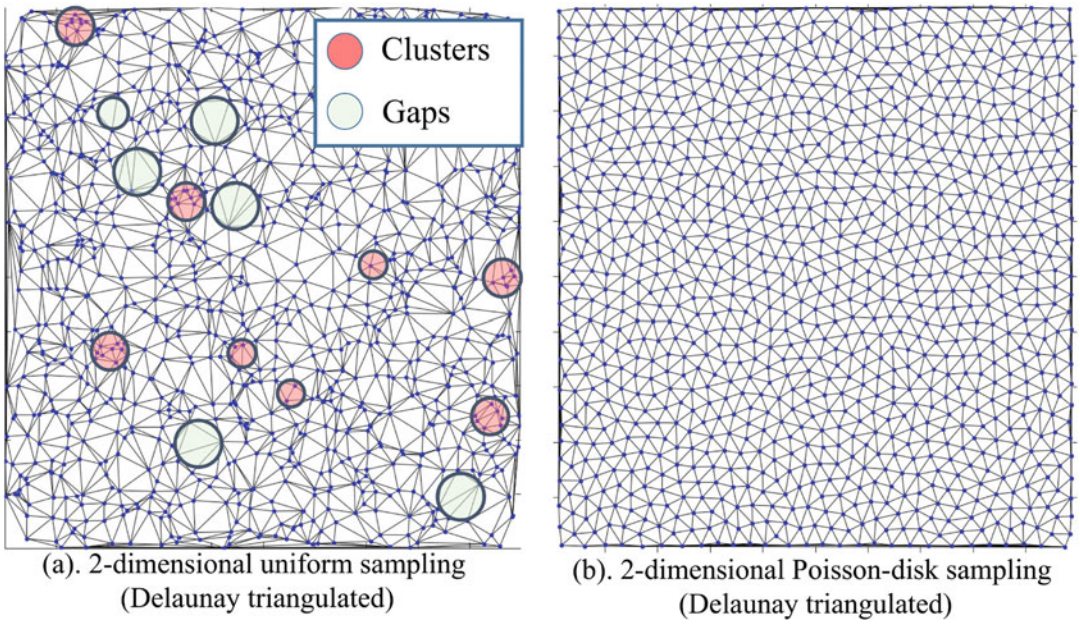
The Poisson-disk sampling distribution is a sampling strategy that will ensure each sample to be independent to each other with a certain random distribution, while also keep a certain minimum distance r from each other. Cook (1986) is one of the earliest works that presented Poisson-disk sampling as a proven pattern for antialiasing. It is proved that Poisson-disk sampling is capable of generating high-quality geometry and image quality in other applications such as remeshing and image synthesis as well.

Evaluation of Samples

It is common to use the **power spectrum** to analyze the features and quality of a sample set. The



Poisson-Disk Sampling: Theory and Applications, Fig. 1 (**a**) 1024 2D random sampling pattern with uniform distribution and (**b**) 1024 Poisson-disk samples in 2D space (Note the differences between different sampling strategies)



Poisson-Disk Sampling: Theory and Applications, Fig. 2 (**a**) Delaunay triangulation of 1024 uniform random samples in 2D space, notice the gaps and clusters that will harm the quality of the samples and (**b**) 1024 Poisson-disk samples in 2D space, which is randomly distributed while evenly scattered

method is introduced by Ulichney (1988) and was discussed in detail by Lagae and Dutre (2008). The use of the power spectrum in sample analysis is often called spectral analysis. We also use the formulation in Lagae and Dutre (2008) and present the N samples as sums of δ functions (x_k represents a sample in the d-dimensional sampling domain):

$$S(\mathbf{x}) = \frac{1}{N}\sum_{k=1}^{N}\delta(\mathbf{x}-\mathbf{x_k}) \tag{1}$$

Thus, the Fourier transform of this function is:

$$f(\mathbf{w}) = \int_D f(\mathbf{x})e^{-2\pi i(\mathbf{w}\cdot\mathbf{x})}d\mathbf{x} \tag{2}$$

$$S(\mathbf{x}) = \frac{1}{N}\sum_{k=1}^{N}e^{-2\pi i(\mathbf{w}\cdot\mathbf{x})} \tag{3}$$

Then we can calculate the power spectrum $\mathcal{P}$ as an important measure of a sample pattern:

$$\mathcal{P} = \left|\sum_{k=1}^{N}e^{-2\pi i(\mathbf{w}\cdot\mathbf{x})}\right| \tag{4}$$

Take 2D samples as an example: the 2D samples will be translated into a 2D power spectrum. A uniform random example will have a constant spectrum while a good sampling pattern will contain less low-frequency energy which is beneficial for most applications. See Fig. 3 for more explanations of the power spectrum and it is radial average as a 1-d measurement.

Poisson-Disk Sampling: Generation

Dart-Throwing

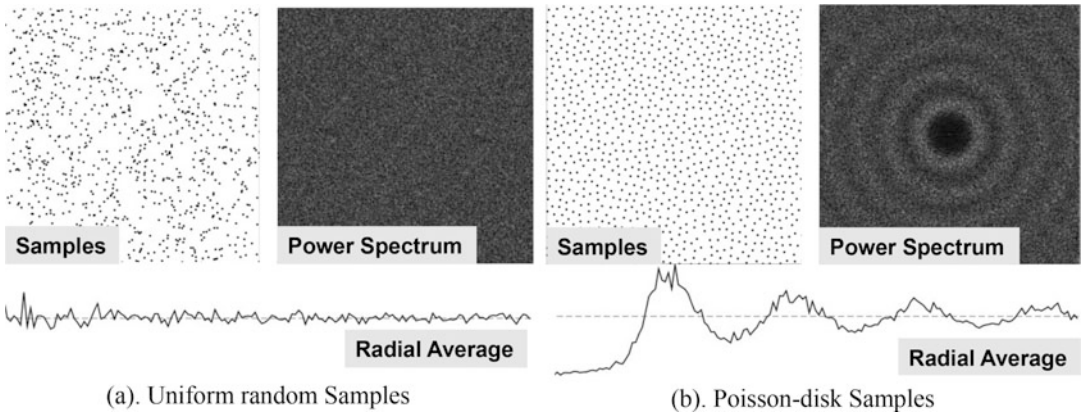
The most fundamental algorithm to generate a Poisson-disk sample pattern in arbitrary dimension is called **Dark-Throw** algorithm as introduced in (Dippé and Wold 1985) and (Cook 1986). The process of the algorithm to generate a Poisson-disk sampling with a conflict radius r is:

1. Throw a d-dimensional sample *dart* into the domain
2. Accept the *dart* if it's not within radius r
3. Reject the sample if it is within radius r from any other sample
4. Repeat the process until no samples will be accepted

There is an obvious problem with the naive dart-throw strategy: the convergence of such an algorithm is very difficult. The rejection rate will increase dramatically as more and more space is occupied by other samples. There are several variations in dealing with such performance issues to make the sampling time reasonable.

Variations of Dart-Throwing

There are some early works that try to split the space and manage gaps explicitly in order to



Poisson-Disk Sampling: Theory and Applications, Fig. 3 (**a**) The power spectrum of a uniform random sample is white noise and the radial average only contain constant or DC(direct current) information, and (**b**) the power spectrum of Poisson-disk samples will have such "ring" effects with low DC in low frequency area and high DC in high frequency area

increase the acceptance rate of insertion. A thorough survey of the earlier dart-throwing based method is in Lagae and Dutre (2008).

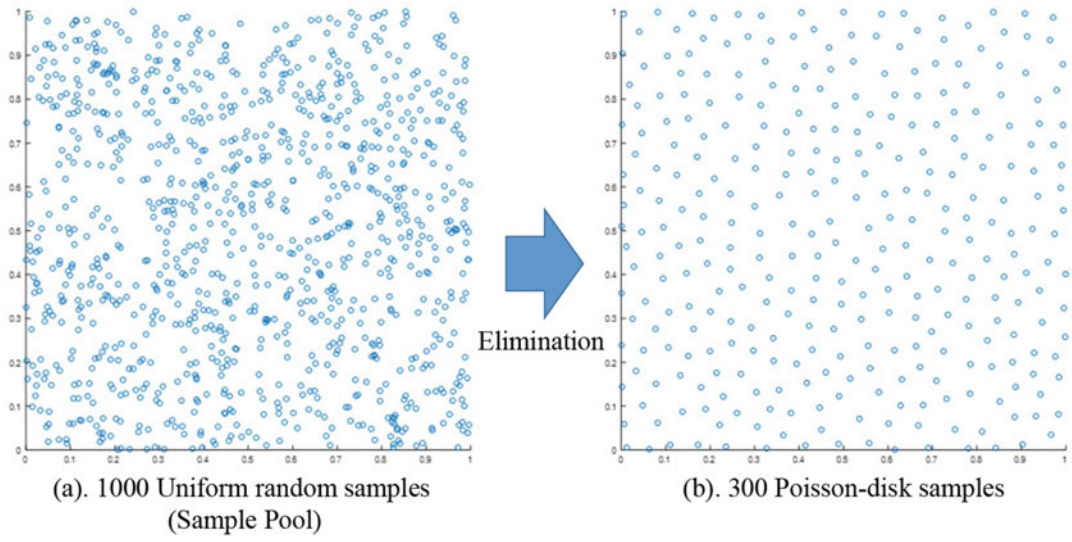
There are methods that try to manage explicit gaps more efficiently. Ebeida et al. (2011) proposed an efficient Poisson-disk sampling algorithm that will ensure maximal coverage, which means that no further sample can be inserted without violating the conflict rule. The work from the same author Ebeida et al. (2012) is a more elegant algorithm that manages active gaps in a quad-tree or high dimensional spatial subdivision data structures, which is much easier to construct and maintain. A more specific study on gap management is conducted by Yan and Wonka (2013), who analyzed the gap-related concepts in such a family of Poisson-disk sample generation algorithms and provided a more general framework for gap management techniques.

Gap management aims to reduce the rejection rate in the sampling, while the parallelization of Poisson-disk sampling algorithms will increase performance in the actual implementation of such algorithms on parallel computing models, such as multicore CPUs or GPU with massive SIMD (single instruction, multiple data) execution hardware. For example, Wei (2008) tries to split the space into different phase groups and define parallelism by the number of threads that can throw dart samples in each phase group. Bowers et al. (2010) improved such a parallel scheme to sampling on 2D manifold surfaces.

Sample Elimination

The traditional dart-throwing and its variation mainly focused on reducing the rejection rate, but the elimination based algorithm will reduce the number of samples with a certain strategy until the rest samples satisfy the Poisson-disk sampling rule. Figure 4 shows how a dense uniform sample is converted to a sparse Poisson-disk sample set through an elimination process. The weight-based elimination methods developed by Yuksel (2015) is one of the most simple and elegant algorithms.

Here we will briefly discuss the main idea of a weight-based elimination algorithm. Suppose the target sampling count is N, the elimination-based method will first generate kN (empirically k will be larger than ten) uniform random samples in the sampling domain (high dimensional Euclidean space or manifold space), then calculate a *weight*



Poisson-Disk Sampling: Theory and Applications, Fig. 4 (**a**) 1000 uniform samples and (**b**) Eliminate 700 samples from the uniform random samples with a certain rule (e.g., weight-based elimination), the 300 samples left will appear to be Poisson-disk sampling pattern

parameter for each sample by how close its neighbors are. Samples will then be organized in a priority queue by the weight parameters. Samples with higher weight will be eliminated from the set. Each elimination will cause several updates of weights in the priority queue. The elimination will go on until the target sample count N is reached.

Ying et al. (2013) further discussed parallel elimination by defining how the explicit phase group subdivision can be re-interpreted as intrinsic parallelism that used a unique priority number for each sample to automatically form the recursive independent subsets in the sampling process.

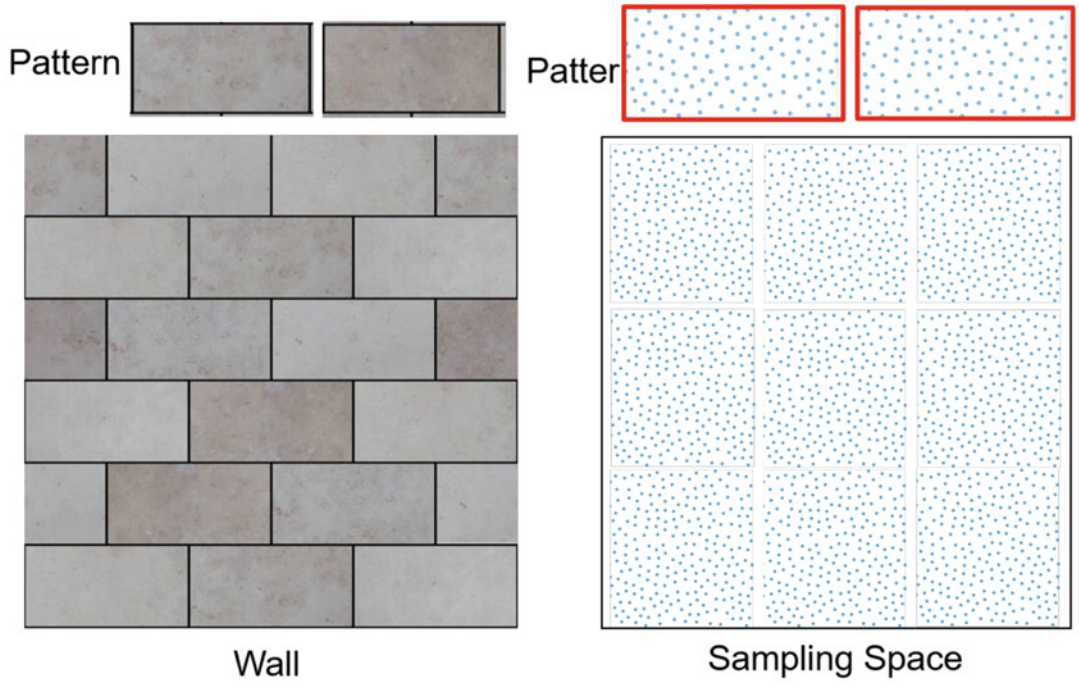
Tile-Based Methods

Another approach to efficiently generate Poisson-disk samples is by tile-based methods. Several tiles filled with Poisson-disk samples will be pre-generated and they will be used as a construction unit to generate larger sample sets by tiling the sample tiles in the sampling domain. Figure 5 is a simple illustration of how tile-based methods work.

Cohen et al. (2003) is an early pioneer work in tile-based Poisson-disk sampling. The use of recursive Wang tile in Kopf et al. (2006) significantly increased the sampling rate while still be able to control the bias and aliasing. Lagae and Dutré (2005) developed a texture basis function that enables the real-time generation of an infinite amount of Poisson-disk distributions of arbitrary size through tiling.

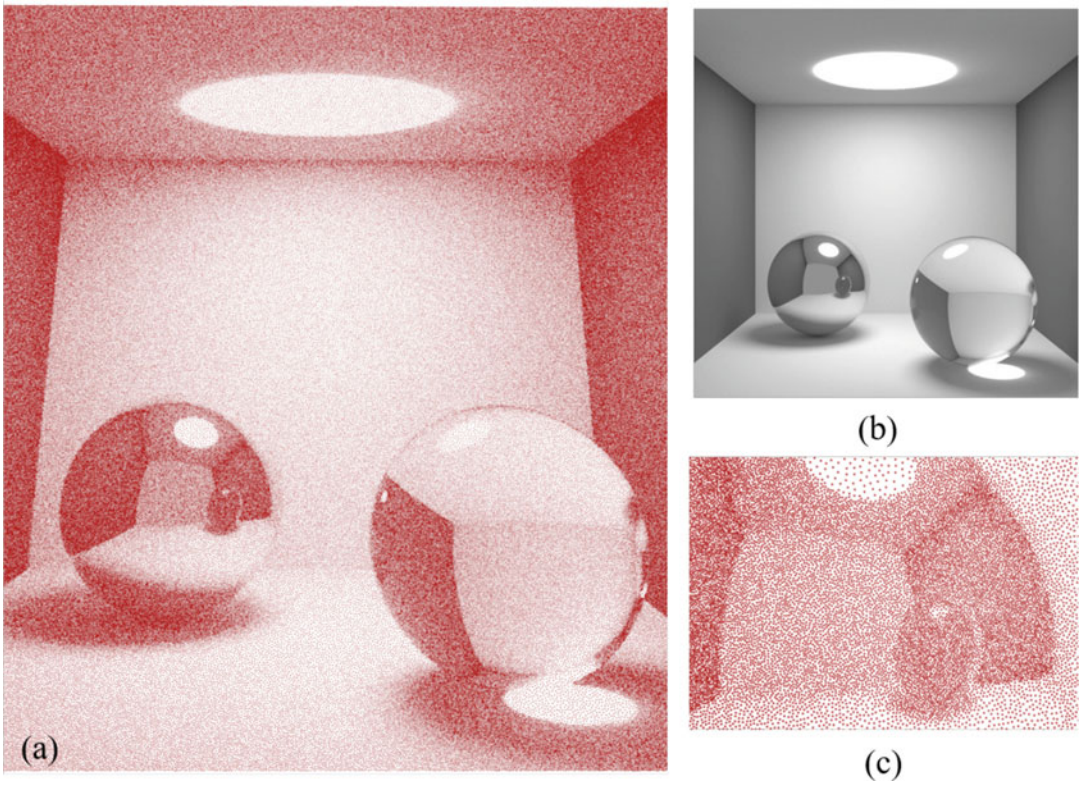
Applications

As a well-known stochastic sampling strategy, Poisson-disk sampling performs well in many applications in computer graphics related fields. It is proved that the blue-noise sampling pattern (which means sample patterns with low DC energy during low frequency and high DC energy during high-frequency domain in the power

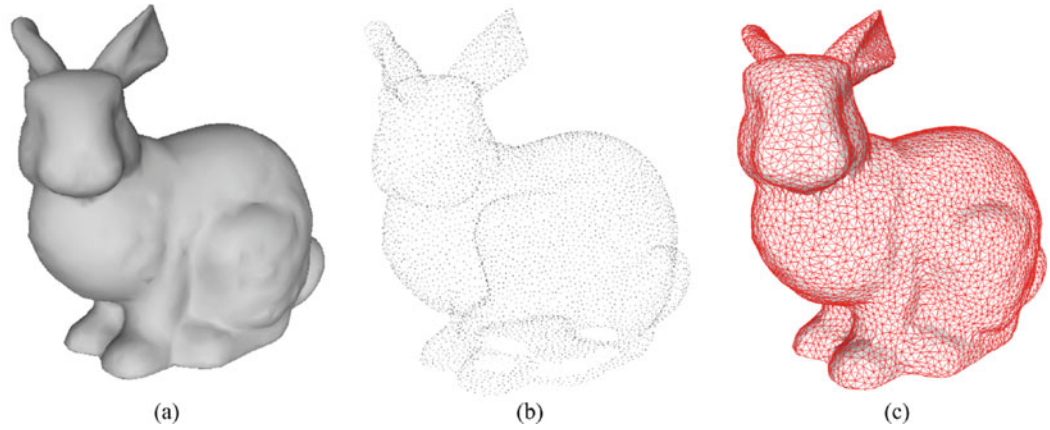


Poisson-Disk Sampling: Theory and Applications, Fig. 5 Basic idea of the tiling-based method. To tile a sample domain, we need to prepare the sample pattern and the tiling method, similar to the tiling process of a wall. It is important to tile in an aperiodic and random way to avoid extra aliasing and bias

Poisson-Disk Sampling: Theory and Applications, Fig. 6 Variance will be revealed as noise in human visual in rendering. A Poisson-disk sampler in (**a**) can help alleviate variance problem from a uniform random sampler in (**b**)s Killeroo model courtesy of headus/Rezard



Poisson-Disk Sampling: Theory and Applications, Fig. 7 (**a**) is the stippling result. Note how Poisson-disk samples with different density is shading the image, and (**b**) is the original black and white image. (**c**) is the enlarged local feature



Poisson-Disk Sampling: Theory and Applications, Fig. 8 (**a**) shows the surface of the famous model Stanford bunny, and (**b**) is a set of Poisson-disk samples on the surfaces. These samples will then be triangulated with algorithms such as ball pivot base reconstruction to form a mesh with better statistics as is shown in (**c**)

spectrum graph) will have a low discrepancy, while still keep good randomness to help avoid aliasing and bias. Here we will give a simple introduction of how Poisson-disk sampling patterns can be beneficial in various applications.

Rendering

Poisson-disk sampling patterns perform well in antialiasing thanks to the low discrepancy and high randomness feature. Figure 6 shows some examples and comparisons of using Poisson-disk samples in various stages during the pipeline of off-line rendering.

Image Stippling

Image stippling is an application that creates image shading only with small dots. The variation of density of dots will represent different colors of the image. Image stippling can be performed using varied radius Poisson-disk samples, which means that for each sample, the conflict radius can be different according to a weight or color function assigned to it. Figure 7 is an example of stippling a rendered result in a path tracer of the famous Cornell box scene.

Remeshing

Remeshing is a set of methods to find a better discrete representation of a given surface. In many computer graphics applications, a good mesh will contain roughly equal edge length and triangle area. The Poisson-disk samples on 3D surfaces will help such a process of finding a good mesh from the underlying surface. Figure 8 shows a simple remeshing process.

Conclusion

In this entry, we introduced the basic theory and related applications of Poisson-disk sampling. We summarize three different generation techniques that can alleviate expensive dart-throwing. As one of the most important blue-noise sampling strategies, Poisson-disk sampling is widely used in various fields. Readers can check survey literature such as Yan et al. (2015) for further study.

Cross-References

▶ Delaunay Triangulation
▶ High-Performance Many-Light Rendering
▶ The New Age of Procedural Texturing

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Pokémon

► Pokémon and World Championships

Pokémon and World Championships

The History

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Synonyms

Pokémon; Pokémon Trading Card Game; Pokémon Video Game Championships; Pokémon World Championship

Definition

The Pokémon World Championship (PWC) is an annual tournament for the ranked Pokémon video game qualifiers and the trading card games' best players.

The Pokémon Trading Card Game (TCG) is a collectible card game based on the Pokémon franchise by Nintendo.

The Pokémon Video Game Championships (VGC) are a series of tournaments worldwide for Pokémon players to complete for prizes.

Introduction

The Pokémon World Championship debuted in 2004 for the trading card game and it quickly grew in popularity with the inclusion of the video game series in 2009. The championship is separated into three divisions based on age: Junior (ages 13 and below), Senior (ages 14–17), and Masters (ages 18 and up).

To qualify for both the Trading Card Game and Play! Pokémon divisions, you must win a certain number of *Championship Points* at Championship-sponsored events. The number of

points you need to receive is based solely on how many people are in your region and age division.

To be able to enter and earn points for these Pokémon events, you need to have a Trainer Club Account with a matched Trainer ID in order to opt in.

Nintendo Formed (1889)

Nintendo, originally known as Nintendo Koppai, debuted in Japan on September 23, 1889, as a card company. Specializing in Hanafuda Cards – a type of Japanese playing card – the creator, Fusajiro Yamauchi, believed that his company would grow quickly. He was correct. For more than 100 years, Nintendo has dabbled in taxi services, ramen noodles, and even "love" hotels. Little did he know that Nintendo would become one of the largest video game companies, with an annual gross revenue of over $10 billion.

Nintendo entered the gaming scene in 1975. In 1978, they made their first game for the computer. It was not until the 1980s when they really took off in the video game world when Shigeru Miyamoto helped with the development of Donkey Kong. This would be the beginning of many of their greatest games.

GAME FREAK Started Up (1980s)

GAME FREAK started out as a self-published gaming magazine around the 1980s by Satoshi Tajiri and Ken Sugimori, with Tajiri writing and editing, and Sugimori illustrating. On April 26, 1989, the duo started a video game company in the same name. Although their idea for Pokémon did not take off at first, they were reputable enough to get a job helping Nintendo make games by joining Namco. It was soon after the development of Mendel Palace, also known as Quinty, that they moved on to help Sony make a game called Smartball for the SNES (Super Nintendo Entertainment System). Eventually Nintendo asked for help with the game Yoshi. This game involved moving falling blocks to make familiar looking pictures of Mario enemies. After the success of this game, they continued to help Nintendo for the next few years while making the first Pokémon games on the side.

Creatures Inc. Created (1995)

Creatures Inc. was created on November 8, 1995, from the remnants of the then disbanded Ape Inc. – creators of the Earthbound/Mother series. Creatures Inc. would go on to become a big developer within the Pokémon Company. They were one of the biggest developers for the early Trading Card Game, as well as some of the merchandises. Although it was not the main focus, they also helped with a lot of the 3D modeling for some of the newer Pokémon games.

As of 2019, no one was really sure about Creatures Inc. On December 9, 2019, Creatures Inc., along with Shogakukan, were removed from GAME FREAKs list of business partners on its website. Creatures Inc.'s own website ended its timeline on March 3, 2018. What remains to be seen of this third of the Pokémon Company is yet to be seen.

Pokémon's First Game Released (1996/1998)

Pokémon's first games to release were Pokémon Red and Green. They were released in February 1996 and again in 1998 in the United States as Red and Blue. Its reception was widely popular on release, becoming one of the most bought games for Nintendo's handheld console line, the Game Boy. The premise of Red, Green, and Blue would set the mold for future games. In it, you play as a young boy named Red who is tasked with going around and filling out the Pokédex while also completing the Gym Challenge and becoming the next Pokémon Champion. While doing all these, your character – an 11-year-old boy – also takes it upon himself to help take down the Criminal Organization known as Team Rocket. With 8 Gyms, 151 Pokémon in the Pokédex to find, and countless hours of exploring, Pokémon was quickly gaining attention.

Pokémon, now household name, has had eight generations of games, as well as countless spinoff

games from the main series, such as Pokémon Snap, or Pokémon Rangers. Even though they use the same formula for most of their games, they still continue to sell over millions of copies with each release. In fact, their most recent main game release sold over 20 million units, surpassing Gold and Silver – the Gen II Pokémon games. However, the most sold Pokémon game remains to be Red/Green/Blue, with over 31.38 million units sold as of December 2020.

The Pokémon Company Launched (1998)

The Pokémon Company launched in 1998 by the trio of Pokémon creators: Nintendo Co., Ltd., GAME FREAK Inc., and Creatures Inc. It was originally named Pokémon Center Co., Ltd., but changed its name in 2000 to the Pokémon Company. They control the overall management of the Pokémon brand.

Pokémon's Trading Card Game Developed (1996/1999)

This is the beginning of the Pokémon tournament craze. The Pokémon Trading Card Game (TCG) was developed so that anyone, regardless of age, could enjoy competing with friends, family, and strangers. Beginning in 1996, 102 cards were made by the company Media Factory. Three years after their popularity took off, they were introduced to North America by Wizards of the Coast. Quickly gaining popularity, tournaments were being held, and it was a craze that many people enjoyed and still enjoy today. Whether you are a competitor in the tournaments or just a Pokémon card collector, it was apparent to many, especially the company, how quickly it would grow.

In fact, over 30 billion cards have been printed. What is even more crazy is the amount of money people will spend on cards. Some of the rarer cards would sell for thousands of dollars. This gaining popularity and willingness for people to buy cards were noticeable enough for the Pokémon Company to step in and start the world championship.

Pokémon Organized Play (2003)

Pokémon Organized Play came to be after Wizards of the Coast lost their license to the game in 2003. With this new power over the Pokémon Trading Card Game (TCG), the Pokémon Company International, aka Pokémon USA, started to organize new tournaments, leagues, and prize systems.

The Pokémon World Championship for the TCG (2004)

Although there were technically championships held before Nintendo's takeover of the TCG, the official Pokémon World Championship did not start until 2004. Between 1999 and 2001, Wizards of the Coast would hold the Tropical Mega Battle in Honolulu, Hawaii, every year until the Pokémon Company's eventual takeover of the series.

In order to enter the Pokémon World Championship, you must be chosen for the World Series by meeting a set of qualifications. These qualifications are your overall ratings (i.e., how many points you have gained throughout the season and so on) and how well you did in the previous year's tournament. You also need to have a Trainer Club Account and a paired Trainer ID in order to compete and gain points in tournaments.

The Championship is "set over three days with a last chance qualifier (known to players as The Grinder) on a Friday to fill seats left vacant for various reasons (e.g., no travel, local qualifiers) until all seats are filled. The second day is limited to Swiss Pairings over a set number of rounds, and the top players (16 each in the Junior and Senior Divisions, as well as the top 32 in the Masters division) move onto the Sunday rounds. The format for this final is single elimination, until the finals, which are a best two matches out of three to decide the World Champion," (*World Championships* n.d.). There are also age qualifiers depending on what division you can get into. These are: Junior (ages 13 and below), Senior (ages 14–17), and Masters (ages 18 and up).

PWC Includes VGC in Competition (2009)

The Pokémon World Championship (PWC) debuted in 2009 in San Diego, California. The premise of this tournament was very similar to the Pokémon Trading Card Game (TCG). The main difference is that PWC was a video game and not the card game. There was no Masters Division until 2011. Originally, it was the top 2 who would advance to the finals, but now it is the top 8.

"The most recently released Pokémon game is used for battles. The in-battle rules and banned Pokémon vary from year to year. Usually, the battles are double battles, and each player can use four Pokémon. The event format consists of Swiss rounds, followed by a single elimination tournament. In 2009, the top two advanced to play the finals on Sunday, whereas since 2010, the top eight advance to play in a head-to-head single elimination event to decide the World Champions," (*World Championships* n.d.).

Unfortunately, the 2021 championships for both the VGC and TCG were canceled due to COVID-19. However, the championships were expected to resume in the following year.

POP Changed Its Name to Play! Pokémon (2010)

In 2010, Pokémon Organized Play (POP) changed its name to Play! Pokémon. It continues to operate as the official governing body of the Pokémon Trading Card Game (TCG), the Pokémon Video Game Championships (VGC), the Pokkén Tournament Championships, and the Pokémon World Championship (PWC).

Conclusions

Having captured the hearts of many, and just giving that nostalgic feeling that anyone gets when playing a game from their childhood, Pokémon fans, TCG players, VGC players, and those who simply just like the show are overly thrilled to be celebrating 25 years of the franchise as of 2021. With every new generation, new and younger fans join the competitions, thus leading the Pokémon Company to have the luck of an ever-growing player base. It is without a doubt that Pokémon will continue to influence the game industry.

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▶ Game Venues and Platforms

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Pokémon Trading Card Game

► Pokémon and World Championships

Pokémon Video Game Championships

► Pokémon and World Championships

Pokémon World Championship

► Pokémon and World Championships

Political Communication

► Challenges Facing the Arab Animation Cinema

Political Game Design

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Synonyms

Activist games; Documentary games; Newsgames; Persuasive games; Serious games

Definition

Political game design the exploration of the scope, limits, and possibilities of game design for a politically motivated position. Political games may aim to inform, motivate, or challenge people about politics and let them to engage with different levels of political sphere through gameplay.

Introduction

While earlier examples can be found in the form of games designed for the education of rulers in core principles of military and politics (Von Hilgers 2012); according to Lerner the history of political games and political play can be traced back to the nineteenth century, to the invention of Prussian tabletop wargames. By 1960s mostly cooperative political minded physical games were used by activists both in the USA and in Latin America to achieve political change (Lerner 2014). Political analog games are still used in many areas including urban design and peacebuilding as a tool and a method (Tan 2014; Brynen et al. 2018). The conceptualization and practice of political video games on the other hand starts with 2000s.

Political Video Games

Since mid-2000s game scholars have been arguing for the design of video games for purposes beyond entertainment and particularly for political activism. In 2005, Gonzalo Frasca had predicted that video games "will become an increasingly popular platform for political and social commentary and activism as they become increasingly prevalent in households" (Frasca 2005). Joost Raessens argued that the use of games to foreground social and political issues by collectives of game developers, artists, and political activists would turn a platform for pure fantasy into a medium for social realism and critique (Raessens 2006). Defining videogames as expressive media carrying messages through their procedural and audio-visual representation systems which can simulate real-life processes,

Ian Bogost points out that the persuasive power of videogames could be used by politicians, political parties, policy-makers, as well as activist citizens, nongovernmental organizations, and by journalists for criticizing, explaining and even for provoking political issues (Bogost et al. 2010). Even though they were overshadowed by the rise of social media, in the last decade these predictions have at least partially came true. Since their first use in 2013 in the USA (Bogost 2007), political election games continue to be produced as part of election campaigns in different countries, like France (Saeed 2017) and the UK (Dallison 2017) during the 2017 elections. Designing video games accompanying political activism or reacting to political turmoil in different parts of the world have become a common practice, as seen in Turkey both during the Gezi Park protests in 2013 (Sezen and Sezen 2016) and after the coup attempt in 2016 (Sezen and Sezen 2018). Finally, since 2011 the Syrian civil war and the following refugee crisis have inspired several games investigating this humanitarian crisis from different perspectives (Stuart 2015; Gach 2017). Even though not as prominent as game scholars have predicted, political video games have become a part of the new media landscape.

Types of Political Games

Focusing on many ways, people use games for political purposes, and both analog and digital games, Lerner proposes three main categories: games about politics, play as political action, and games as political action (Lerner 2014). Games about politics are games about political issues which aim to inform and motivate their players. Their simplest form is what might be called a reactionary political game, a game which addresses a timely political issue without delivering a deep analysis or argumentation and has a very short circulation period. Sicart criticizes such games for being design-wise unoriginal and for not providing any contribution to the political discourse (Sicart 2014).

Play as political action on the other hand inserts game design principles into political practice. One of its famous examples could be considered *the Theatre of the Oppressed* performances by Augusto Boal (1985). Comparing games and play in political context, Sicart argues that play constitutes a much stronger expression of political ideas and continues, "because it is play, it can thrive in situations of oppression; because it is play, it can allow personal and collective expression, giving voices and actions when no one can be heard" (Sicart 2014).

Lerner's last category, games as political action, encompasses games designed to achieve political change. These games are not about politics but are a way of doing politics. "Unlike political play. . ." Lerner says, ". . .these games are structured around specific rules, conflicts, and outcomes" and should be considered tools to make political decisions (Lerner 2014). Analog games used in design processes and activist street games should be considered under this category. The former can be used in areas such as urban politics and the latter can be used as a direct method to achieve political change in the streets and in face-to-face meetings.

Design of Political Games

While the designers' political views may be influential on the level of in-game political agency and critical perspectives of political games, one of the factors affecting these features is time. A game's temporal distance to its topic could be a significant factor over its design choices and consequently over the production specifics, complexity of the game mechanics, stylistic features, and gameplay duration. A short temporal distance between the event and the release of the game usually results with a quick, emotional response as seen in reactionary games. If temporal distance between the event and the release of the game is longer, and during this interval the issue is continued to be discussed and still relevant in the society, it is expected the game as part of the surrounding media ecology might express a political position and contribute to the ongoing discussions. *September 12th*, *Peacemaker,* or *Syrian Journey* might be seen examples of such

process. If though the issue at hand had lost its eminency and relevance, meaning the issue has been closed for the society we may see games akin to political documentaries, analyzing the issue from different perspectives. *1979 Revolution: Black Friday* on 1979 Iranian Revolution or *Ihtilal* (Revolution) on the 1960 coup d'etat in Turkey could be examples.

Going beyond the concept of political themes and events, Mary Flanagan and Helen Nissenbaum propose the term "conscientious designer" to describe those who accept to embody and implement ethical and political values when they design and build systems including games. Political values can be described as arrangements of power and authority, which define relationships within and between societies, such as justice, equality, security, cooperation, tolerance (Flanagan and Nissenbaum 2014). It can be argued that political values are the building blocks or components of individual political themes and issues. A conscientious designer uses game design elements which not only have cultural, ethical, and political resonances, but also are experienced by the players to reflect on political values. According to Flanagan and Nissenbaum, some of these elements can be listed as follows: Narrative premise and goals, characters, actions in games, player choice, rules for interaction with other players and nonplayable characters, rules for interaction with the environment, point of view, rewards, and game maps (Flanagan and Nissenbaum 2014). A conscientious political game designer should be able to analyze individual political issues to identify the values shaping it and later use the game design elements, which would enable her to reflect on them.

Conclusion

There is no single relationship between games and politics, and these relationships continue to grow up in many unexpected new ways. Media outlets, political actors, and institutions explicitly embrace the experimental possibilities of games. Political games are still not a key medium in today's political media landscape, but a unique part of it.

Cross-References

- ▶ Narrative Design
- ▶ Serious Games

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Polygonal Modeling

► Modeling and Mesh Processing for Games

Porting

► Redesigning Games for New Interfaces and Platforms

Pose Estimation

► Fall Risk Detection in Computer Vision

Position Based Dynamics

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Definition

Position based dynamics is a fast, stable, and controllable simulation technique. It directly manipulates the vertex positions of object meshes instead of forces or impulses and can model various dynamic and interactive effects of objects such as rigid body, soft body, cloth, or fluids.

Introduction

Physically based simulation has been an important and active research field in computer graphics. In recent decade, it has become an indispensable component in movies, video games, or interactive applications. In addition, with the rapid growth of the computational capabilities of CPUs and GPUs, there are more and more demands for real-time complicated simulation effects.

The classic simulation method is based on Newton's law of motion to accumulate internal and external forces acting on an object at the beginning of a time step. Then a numerical integration technique like explicit or implicit Euler integrator is further applied to estimate new velocity, and then position at the end of a time step. The former is conditionally stable and accurate if a small time step is adopted. In contrast, the latter is unconditionally stable even though a large time step is adopted, but inaccurate. In order to achieve a trade-off between them, position based method simply adopts a fast semi-integrator, symplectic Euler, to evaluate external force like gravity. Furthermore, instead of gathering internal forces to compute acceleration and velocity, the vertex position is directly manipulated and controlled to solve internal constraints, like stretching, bending, or volume constraint, and collision constraints such as mutual-collisions between objects or self-collisions of an object. Consequently, this method does not only bring the speed and visual plausibility but also the controllability on attached objects or collision handling. Some well-known real-time physics engines such as *PhysX*, *Bullet*, and *Havok* all have integrated the position based method into their systems to simulate soft body or cloth dynamics.

In this entry, we mainly introduce the position based dynamics method (PBD), presented by Müller et al. (2007), and refer to new emerging techniques based on the former.

Overview of Algorithm

PBD presented a particle-based model which combines internal and collision constraints. A deformable object is represented by a set of N particles and a set of M ($M_{\text{inter}} + M_{coll}$) constraints including a fixed number of internal constraints (M_{inter}) and an unfixed number of collision constraints (M_{coll}). At each time step (Δt), the simulation procedure is performed as follows. Before entering the simulation loop, for all N particles, we initiate the current position (x), velocity (v), and mass (m) of each particle to its beginning variables.

1. Gather and accumulate external forces ($f_{ext}(x_i)$) acting on particle i. These forces include

gravity and other forces that are unable to be converted to position based manipulation.
2. Update new velocity (v_i) and predicted position (x_i') by the symplectic Euler method: $v_i = v_i + \Delta t \frac{f_{ext}(x_i)}{m_i}$, and $x_i' = x_i + \Delta t v_i$.
3. Perform discrete or continuous collision detection to collect all overlapping geometries, and generate M_{coll} collision constraints (see section "Collision Constraints").
4. Iteratively solve a set of M constraints one after another in a Gauss-Seidel type fashion, until the solver loop reaches the maximal predefined iteration. While solving a constraint, those predicted positions (x') of particles related to this constraint are all corrected to satisfy the constraint condition (see section "Internal Constraints").
5. After solving constraint loop, the predicted position(xi′) is used to update the velocity (v_i) accordingly, and then set back to the current position (x_i): $v_i = \frac{x_i' - x_i}{\Delta t}$, and $x_i = x_i'$.
6. Lastly, these velocities of colliding particles involved in the collision constraints need to be further modified according to friction and restitution coefficients.

Internal Constraints

An object model does not only consist of a set of particles but also a set of internal constraints such as stretching, bending, or volume constraints. These constraints are to simulate various object materials like soft body or cloth by building an equilibrium system which connects different particles together based on the constraint type. Instead of adopting a classic mass-spring model to evaluate a force based result, the system directly controls the positions and displacements of those particles to satisfy the constraint conditions. In addition, it also must conserve both linear and angular momentums. This means that any rotating or translating the particles does not change the equality of the constraint function $C(x + \Delta x) = 0$. Δx stands for the corrected displacements of all particles, i.e., $[\Delta x_1, \ldots, \Delta x_N]^T$.

The constraint function can be further derived and approximated by the following equation:

$$C(x + \Delta x) \approx C(x) + \nabla_x C(x) \cdot \Delta x = 0$$

where $\nabla_x C(x)$ is a gradient vector and means the maximal change's direction. By restricting Δx to be in the direction of $\nabla_x C(x_1, \ldots, x_N)$, we can derive

$$\Delta x = -\frac{C(x_1, \ldots, x_N)}{|\nabla_x C(x_1, \ldots, x_N)|^2} \nabla_x C(x_1, \ldots, x_N)$$

Then, for the corrected displacement of an individual particle i with an inverse mass $w_i = 1/m_i$, we have

$$\Delta x_i = -\frac{w_i C(x_1, \ldots, x_N)}{\sum_j^N w_j |\nabla_{x_j} C(x_1, \ldots, x_N)|^2} \nabla_{x_i} C(x_1, \ldots, x_N)$$

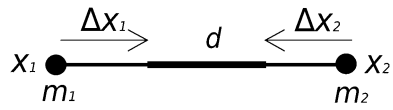
In order to represent the stiffness strength of an object material, the stiffness parameter $k \in [0 \ldots 1]$ is incorporated into the above constraint function. Then, it becomes

$$\Delta x_i = -k' \frac{w_i C(x_1, \ldots, x_N)}{\sum_j^N w_j |\nabla_{x_j} C(x_1, \ldots, x_N)|^2} \nabla_{x_i} C(x_1, \ldots, x_N)$$

where $k' = 1 - (1 - k)^{1/s}$ and s is the iteration count of a constraint solver. Instead of directly multiplying Δx_i by k, k' makes k independent of the solver and more predictable.

Stretching Constraint

For each edge of a triangle mesh, a stretching constraint is built to control the movement of both its vertices, x_1 and x_2. This constraint can be represented as a distance constraint function $C(x_1, x_2) = |x_1 - x_2| - d$, where the scalar value d is the initial distance between x_1 and x_2. Such as Fig. 1, both vertices are projected to the direction of gradient vector $\nabla_x C(x_1, x_2)$, i.e., $\nabla_{x_1} C(x_1, x_2) = n$, and $\nabla_{x_2} C(x_1, x_2) = -n$, with $n = (x_1 - x_2)/|x_1 - x_2|$. Thus, we can get the final displacements as follows:



Position Based Dynamics, Fig. 1 The projection of distance constraint

$$\Delta x_1 = -\frac{w_1 C(x_1, x_2)}{\sum_{j=1}^{2} w_j \left|\nabla_{x_j} C(x_1, x_2)\right|^2} \cdot$$

$$n = -\frac{w_1(|x_1 - x_2| - d)}{w_1 + w_2} \cdot \frac{x_1 - x_2}{|\, x_1 - x_2 \,|}$$

$$\Delta x_2 = +\frac{w_2 C(x_1, x_2)}{\sum_{j=1}^{2} w_j \left|\nabla_{x_j} C(x_1, x_2)\right|^2} \cdot$$

$$n = +\frac{w_2(|x_1 - x_2| - d)}{w_1 + w_2} \cdot \frac{x_1 - x_2}{|\, x_1 - x_2 \,|}$$

Bending Constraint

For each pair of adjacent triangles T1(x_1, x_2, x_3) and T2(x_1, x_4, x_2) such as Fig. 2, we generate a bending constraint with constraint function:

$$C(x_1, x_2, x_3, x_4) = \cos^{-1}(\mathrm{n}_1 \cdot \mathrm{n}_2) - \varphi_0$$

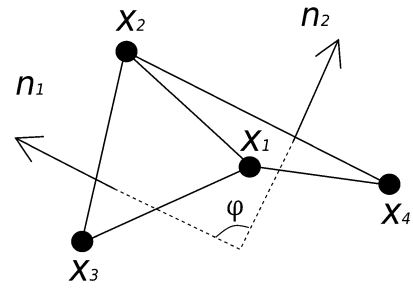
where $n_1 = \frac{(x_2 - x_1) \times (x_3 - x_1)}{|(x_2 - x_1) \times (x_3 - x_1)|}$, $n_2 = \frac{(x_4 - x_1) \times (x_2 - x_1)}{|(x_4 - x_1) \times (x_2 - x_1)|}$, and φ_0 is the initial dihedral angle between T1 and T2. The gradient $\nabla_x C(x_1, \ldots, x_4)$ shows as follows:

$$\nabla_{x_4} C(x_1, \ldots, x_4) = \frac{x_2 \times n_1 + (n_2 \times x_2) d}{|x_2 \times x_4|}$$

$$\nabla_{x_3} C(x_1, \ldots, x_4) = \frac{x_2 \times n_2 + (n_1 \times x_2) d}{|x_2 \times x_3|}$$

$$\nabla_{x_2} C(x_1, \ldots, x_4) = -\frac{x_3 \times n_2 + (n_1 \times x_3) d}{|x_2 \times x_3|} - \frac{x_4 \times n_1 + (n_2 \times x_4) d}{|x_2 \times x_4|}$$

$$\nabla_{x_1} C(x_1, \ldots, x_4) = -\nabla_{x_2} C(x_1, \ldots, x_4) - \nabla_{x_3} C(x_1, \ldots, x_4) - \nabla_{x_4} C(x_1, \ldots, x_4)$$



Position Based Dynamics, Fig. 2 Bending constraint

where $d = \mathrm{n}_1 \cdot \mathrm{n}_2$. Then the final correction Δx_i is as follows:

$$\Delta x_i = -\frac{w_i \sqrt{1 - d^2}\, C(x_1, \ldots, x_4)}{\sum_{j=1}^{4} w_j \left|\nabla_{x_j} C(x_1, \ldots, x_4)\right|^2} \cdot \nabla_{x_i} C(x_1, \ldots, x_4)$$

Volume Constraint

For each closed triangle mesh, a volume constraint is built to maintain its volume and pressure. This constraint function refers to all N particles of the mesh.

$$C(x_1, \ldots, x_N) = \left(\sum_{i=1}^{l} \left(x_{t_1^i} \times x_{t_2^i} \right) \cdot x_{t_3^i} \right) - k_{\text{pressure}} V_0$$

Here l is the amount of all triangles. $x_{t_1^i}$, $x_{t_2^i}$, and $x_{t_3^i}$ represent the three particles of triangle i respectively. $k_{pressure}$ is a pressure factor and used to simulate overpressure status, and V_0 is the original volume of the closed mesh. Furthermore, we can derive the gradient vector $\nabla_{x_i} C(x_1, \ldots, x_N)$:

$$\nabla_{x_i} C(x_1, \ldots, x_N) = \sum_{j : t_1^j = i} \left(x_{t_2^j} \times x_{t_3^j} \right) + \sum_{j : t_2^j = i} \left(x_{t_3^j} \times x_{t_1^j} \right) + \sum_{j : t_3^j = i} \left(x_{t_1^j} \times x_{t_2^j} \right)$$

where $j : t_1^j = i, j : t_2^j = i$, and $j : t_3^j = i$ are the

triangle indices containing x_i in first, second, and third place, respectively.

Collision Constraints

Unlike internal constraints (M_{inter}) which are generated once before simulation, collision constraints (M_{coll}) are detected and generated at each time step before entering the constraint solver loop. In other words, the number of collision constraints varies and depends on actual colliding particles. A collision constraint $C(x_v, x_{t1}, x_{t2}, x_{t3})$ is generated and inserted into the system if the vertex (x_v) hits or penetrates into another triangle (x_{t1} , x_{t2} , x_{t3}). Also, due the collision constraint is an inequality constraint, it will not be performed if the collision does not satisfy the condition of $C(x_1, \ldots, x_N) < 0$. There are both continuous collision and static collision handling methods used to solve different collision cases (Müller et al. 2007).

In order to efficiently detect potential collision and self-collision pairs of deformable objects, a spatial hashing table (Teschner et al. 2003) is built. It can early exclude most of collision pairs which are not colliding with each other. Firstly, the predicted positions of particles and AABBs of triangles are discretized to 3D cell indices with respect to a predefined grid cell size. Then, these cell indices are further mapped into 1D hash index. Lastly, we are able to quickly detect if a particle potentially overlaps with any triangles by checking the same hash index.

As for the collision detection between deformable objects and rigid bodies, bounding volume hierarchy (BVH) (Gottschalk et al. 1996) is built and maintained to speed up the process of culling nonoverlapping parts of the objects. BVH is a tree data structure, and constructed by recursively dividing objects into subsets of geometric primitives. In the meantime, these primitives are enclosed into simple bounding volumes, like spheres, AABB, OBB, or k-DOP and stored into the corresponding tree nodes. By doing the tree traversal recursively and performing simple overlapping tests among bounding volumes, it does not only simplify the collision computations but also reduces the number of collision pairs.

Once a vertex-triangle pair has been detected, continuous collision handling (Müller et al. 2007) is then used to check if the vertex has penetrated into the triangle. We shoot a ray ($x_i \rightarrow x_i'$) for vertex i to perform a ray-triangle intersection test. If this ray hits the triangle, we compute the hit point x_{hit} and the triangle's surface normal n_{hit} at this position and judge whether the inequality constraint function is satisfied:

$$C(x_v, x_{t1}, x_{t2}, x_{t3}) = (x_v - x_{\text{hit}}) \cdot n_{\text{hit}} - h > 0.$$

Here h is a collision margin or surface thickness value. When the above constraint is solved, we can compute the correction $\Delta x_v = h - (x_v - x_{hit}) \cdot n_{hit}$. If the ray hits the front side of the triangle, n_{hit} is computed as follows:

$$n_{hit} = \frac{(x_{t2} - x_{t1}) \times (x_{t3} - x_{t1})}{|(x_{t2} - x_{t1}) \times (x_{t3} - x_{t1})|}$$

In contrast, if the ray hits the back side of the triangle, then we get

$$n_{hit} = \frac{(x_{t3} - x_{t1}) \times (x_{t2} - x_{t1})}{|(x_{t3} - x_{t1}) \times (x_{t2} - x_{t1})|}$$

When a ray is completely inside a closed object, continuous collision handling does not work at this case. At this moment, we apply static collision handling (Müller et al. 2007) to compute the surface point x_s, which is closest to x_v, and the surface normal n_s at this position. Lastly, we can have a modified correction Δx_v:

$$\Delta x_v = h - (x_v - x_s) \cdot$$
$$n_s = h - (x_v - x_s) \cdot \frac{(x_{t3} - x_{t1}) \times (x_{t2} - x_{t1})}{|(x_{t3} - x_{t1}) \times (x_{t2} - x_{t1})|}$$

For the collision handling between deformable objects and rigid bodies, if we need two-way interactions, a correction Δx_v is applied to a deformable vertex. Also, an impulse $m_i \Delta x_v / \Delta t$ is simultaneously applied to the rigid body at the hit point.

The Future

Although position based dynamics is fast, stable, and controllable, it has some limits. The Gauss-Seidel type solver handles constraints one by one individually such that the information propagation is slow and hard to converge. Consequently, it makes deformable object stretchier and results in an obvious visual defect, especially when high-resolution meshes are used. Wang (2015) applied a Chebyshev semi-iterative approach to accelerate the convergence.

Another limit is that the constraint stiffness cannot be completely controlled by the user-defined parameter. It also depends on both the time step size and the number of solver iterations. Specifically, constraints become stiffer and stiffer as the number of solver iterations increases, or as the time step size decreases. Recently, Macklin et al. (2016) introduced a total Lagrange multiplier to PBD and allowed solving constraints to be independent of the above factors.

The position based simulation method is not limited to particle-based models. It also has been used to simulate articulated rigid body systems with joint and contact constraints (Deul et al. 2014).

Macklin and Müller (2013) presented an iterative density constraint solver by formulating and solving a set of positional constraints that enforce constant density. It allows similar incompressibility and convergence to modern smoothed particle hydrodynamic (SPH) solvers (Monaghan 1992).

Macklin et al. (2014) modeled gases, liquids, deformable solids, rigid bodies, and cloth as particle-based models connected by constraints. Also, they treat contact and collisions in a unified manner so as to support two-way interactions with one another.

Cross-References

- ▶ Collision Detection
- ▶ Fluid Simulation
- ▶ Position Based Dynamics

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Position-Aware 3D Facial Expression Mapping Using Ray Casting and Blendshape

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Synonyms

Blendshape; Position-aware concept; Ray casting

Definition

The usage of blendshapes is one of the methods to partially automate the animating process therefore reducing the workload of the animators. This

entry presents an improved method of animating facial expressions using a technique that combines blendshape, ray casting, and the position-aware concept. Blendshape is a technique to deform geometries to create the desired geometrical morph. Ray casting is a fast visible surface detection method and position-aware concept allows the tracking of an entity's current location and be sent to other entities for further uses.

Introduction

Translating human facial expression into 3D animation that is believable and realistic usually requires animators to manually create the expressions in a 3D software. Many researchers have been studying on how to lighten the workloads on the animators by automating some parts of the process. This entry focuses on the process of minimalizing the complexity and tediousness of adding facial expressions on motion capture (MoCap) data to make it more realistic.

For this entry, the focus is on dance MoCap data. Some MoCap data that is based on dances have no facial animation. Therefore, there is a need to animate the facial expression of data to make it more realistic and believable. However, adding facial expressions manually is a tedious and time consuming process. Thus, this entry discusses the process of semi-automating part on the animating process using a combination of blendshape, ray casting, and position-aware concept.

Blendshape

Blendshape is a technique to deform geometries to create the desired geometrical morph. It is the most common way of deforming facial meshes to create various facial expressions. It is supported by popular 3D modeling software like Autodesk Maya, Autodesk 3DS MAX, and Blender. Usually, modelers often have to create a large library of hundreds of blendshape targets to achieve maximum range of facial expressions to ensure that the character's expressions can be as realistic as possible. For example, the character Gollum from Lord of the Rings blockbuster movie series have a total of 946 blendshape targets (Lewis et al. 2005). On top of that, it is an animator's job to animate those blendshapes which requires more work and time.

Blendshapes have weights which controls the intensity of the expressions. This is usually controlled by sliders or input boxes (Lewis et al. 2014). The flexibility of blendshape is what makes it an intuitive and natural approach to animate facial expression. Using this information, it is possible to map a facial expression by transitioning from an expression to another expression by utilizing the blendshapes in a 3D model. Figure 1 shows an example of blendshape presets. These expressions are stored within the model itself and can be set by changing the weights of the desired expressions.

Aside from manually creating blendshape targets, facial motion capture can also be used to generate blendshape targets. This includes marker-based and markerless motion capture systems. An example of marker-based is the cross-mapping motion capture data by Deng et al. (2006). This system requires a complex and expensive setup but it can generate a high quality dataset. With markerless systems, the setup is less complex and cheaper but the tradeoff is the data generated is lower in quality and usually contain a lot of noises. An example of markerless system is by Saito (2015) whereby she used a combination of Brekel Pro Face, Autodesk Maya 2013, and Autodesk MotionBuilder 2013.

3D Object Detection Using Ray Casting

Ray casting is a technique that has been used for many years to solve computer graphics problems. It was first introduced by Roth (1982) whereby he described the method of rendering constructive solid geometry model. Although it was introduced as a rendering method, ray casting can also be used for other purposes such as object detection and visible surface detection. One of the most notable usages of this technique is in video games such as Wolfenstein 3D and Doom (Vandevenne 2004). Ray casting works by

Position-Aware 3D Facial Expression Mapping Using Ray Casting and Blendshape, Fig. 1 Blendshapes (Lewis et al. 2014)

projecting a line from a model as the view vector. The line will be used for detecting other objects it meets. If the line intersects another object, the system will trigger any event that has been set beforehand. Figure 2 shows an example illustration of how a ray cast works.

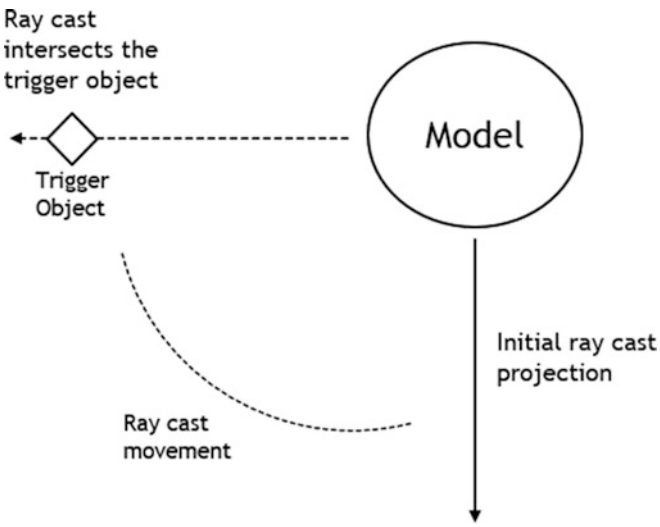
Usually the line represents the view vector of the model. When it intersects the trigger object, the programmer can set the event call for further actions.

Position-Aware Concept

Position or location awareness on a large scale is the technology to track and deliver a device's physical location to other entities such as a user or application. It enables modern devices such as smartphone to share the current geo-location to other users (Bao et al. 2012). This is majorly used in map applications such as Google Maps and Waze. This concept is also used in video games for crowd simulation and Artificial Intelligence (AI) pathfinding. The AI must communicate with other AI and determine their positions to avoid collision. Ondřej et al. (2010) proposed a vision-based steering approach whereby the AI is given a line of sight to determine the other AIs in its surroundings. This ensures that the AI is aware of its current position in the environment and is able to avoid collision with other AI. This can be further improved by implementing human-like gaze to the AI (Narang et al. 2016) which will make the AI have a wider area of viewing since it mimics the vision span of a real human instead of having a straight line vision only. Therefore, this gives more information about its surrounding to make better decision.

Combination of Position-Aware and Ray Casting

Ray casting is a fast technique that is suitable for real time calculations. The idea of combining ray casting with position-aware concept was demonstrated in the 2017 video game titled NieR: Automata developed by PlatinumGames, Inc. In this video game, the sound engineer, Kohata Shuji (2018) developed a sound solution system based ray casting. The goal of this system is to allow the game to simulate reverb and ambience sounds as accurately as possible while maintaining a low cost performance impact. The system projects multiple rays randomly from the player on every single frame. Every time the rays intersect with the objects in the environment, the system would temporarily record the collision points and the sound engine will produce the appropriate sounds. This enables a more immersive and satisfying gameplay.



Position-Aware 3D Facial Expression Mapping Using Ray Casting and Blendshape, Fig. 2 Ray cast example

From this system, the idea of combining ray casting and position-aware concept can be applied to 3D character expression. This technique works by having a ray casted from the face of a 3D model that contains the blendshapes of the expressions and detecting markers designated around the model and maps the correct expression according to the markers. The position-aware aspect of this technique is that the marker's position will determine where the model needs to face for the expression to change. Markers can be placed on specific positions. Then a ray can be casted from the head of the model and at any time the ray intersects with the marker the facial expression will automatically be animated.

Conclusion

In this entry, several techniques and methods that are the component of facial expression mapping using the combination of ray casting, blendshape, and position-aware concept were discussed. This technique manipulates the facial blendshape of a 3D model and considers the position-aware aspect in which the facial expression is changed according to specific location the 3D head model is facing. By using this technique, it is possible to reduce the workload of animators by semi-automating the process.

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Position-Aware Concept

▶ Position-Aware 3D Facial Expression Mapping Using Ray Casting and Blendshape

Post-Digital

▶ Post-Digital Graphics in Computer Games

Post-Digital Graphics in Computer Games

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Synonyms

Nonphotorealistic rendering; NPR; Post-digital

Definition

Post-digital graphics is a computer game aesthetics that makes use of nonphotorealistic rendering (NPR) inspired by analogue art and craft. The decision of implementing post-digital graphics is often influenced by budget reasons, but is also a choice of design leading to specific aesthetic effects.

Introduction

The post-digital paradigm emerges in a moment when digital technology is endemic and plays a central role in contemporary culture. Every individual in the West continually carries along a powerful computer used to constantly translate their life into digital data (pictures, GPS positions, social relations, etc.). The significance of physical space is questioned by online services allowing citizens to interact with institutions, public administration, banks, and offices without the need to actually travel there. Products such as books, video games, films, and music are increasingly dematerialized and transformed in digital goods.

This digital saturation, after a period of enthusiasm, has started to lead to an inverse tendency: post-digital. According to Cramer (2015) the contemporary disenchantment with digital information systems and technological tools entails a revival of "old" media and artifacts, such as vinyl discs and typewriters. Computer games are also touched by this trend, which gave birth to games such as *Cuphead Don't Deal with the Devil* (MDHR 2017) or *Future Unfolding* (Spaces of Play 2017).

Post-Digital in Indie Gaming

Most of games that exploit a post-digital aesthetics are indie games. There are certainly some exceptions – e.g., *Borderlands* (2 k games 2009) – but the indie scene has more to gain using this graphics.

In the last few years, independent games acquired a stable identity, overcoming the "commercial" definition of "indie" and facing what, according to Juul (2014), has been the biggest game design challenges of indie developers: that of creating their own, specific *style*.

Indie game design faces budget limitations that spur developers to explore alternative solutions and avoid creating low-quality imitations of big-budget games. The small productions of indie games, then, turn naturally to the simpler, yet still efficient, rendering techniques used in games from the 1980s and 1990s. These techniques are obviously easier and cheaper to

implement, even if this pragmatic consideration is only part of the picture. In fact the rise of the indie style described by Juul (Op. cit.) is also due to the appeal that this kind of aesthetics can exercise on players.

The keyword here is "retro gaming," a trend driven by *nostalgia* where games aim, with their aesthetics and gameplay, at creating the illusion of a temporal extension and of bringing back the players to the "good old times."

"Pixilated" aliased graphics accompanied by chiptune music, therefore, became very popular in indie gaming. It is a celebration of *digitalness* that does not hide the digital nature of the game, but exhibits it proudly, answering to the nostalgia for a past state of technology and gaming. Nevertheless, retro gaming should be considered as a first symptom of the digital saturation. It is true that it celebrates the technological and artificial aspect of computer games, but in doing so it also criticizes photorealism, and therefore the (con)fusion between reality and the digital world.

Beyond Realism

Already in 2003 Masuch and Röber, in a somewhat prophetical paper, used several arguments to promote the use of rendering styles alternative to photorealism and foresaw the fall of the totalitarian rule of realism and the rise of a new taste for more dream-like graphics.

According to the authors being "realistic" is not simply a matter of visual resemblance with reality, but also a matter of internal coherence, a feature necessary to give to the virtual world a characteristic of believability. In computer games photorealism is, in fact, less relevant than *immersion,* which depends mainly on the consistency of the graphical representations and on the behavior of in-game physics.

Perhaps surprisingly, NPR techniques are often very believable, as they feel more natural and easy to perceive, and therefore are very good at triggering immersion. Their nonrealistic nature allows a higher amount of deviations without disrupting the image or breaking the atmosphere: ironically, less realism leads to more believability.

NPR games, then, may not "look" as real as photorealistic ones, but are more believable and can be used for artistic purposes: they are able to simulate the style of different media (e.g., comics), and may strengthen the storytelling by shaping the style used throughout the game to evoke emotions, or to establish certain moods.

Post-Digital and Analogue Aesthetics

The intersection of NPR, indie games' typical nostalgia, and post-digital taste is analogue *aesthetics:* a graphic alternative whose influence is becoming more and more important in independent games. Hand-drawn or hand-drawn-like graphics that do not appear (or sometimes are not) digitally generated are increasingly popular.

Developers might opt for a crayon-like rendering (see *Crayon Physics Deluxe* 2009 Petri Purho) or for literally hand-drawn backgrounds and characters (*The Banner Saga* 2014, Stoic); in all cases the digital nature of video games is hidden, denied, while the fictitious nature of the game is brought to the foreground.

Analogue aesthetics, then, on the one hand goes in the opposite direction to photorealism, stressing its unreality and its distance from everyday life, and on the other hand is in open contrast with pixelated graphics of retro gaming because it hides the digital nature of the game under an analogue appearance.

Using analogue aesthetics may have several benefits. It is a way of offering a more nuanced emotional palette and to create original and pleasurable dream-like visuals. It boosts immersion without losing any believability, as long as the graphics are coherent with their own assumptions.

The post-digital flavor of analogue aesthetics should not be considered as a sort of Luddite reaction to digitalness advocating paradoxically calling for a nostalgic return to analogue play. It is more likely the product of a change of paradigm that normalizes digital systems (and does not see "digital" as synonymous of "progress") and therefore is prone to hybridize them with a renewed taste for the analogue.

In other words, after a period where everything that was digital was perceived as more

A screenshot from *Lumino City* (2014, State of Play)

prestigious, the trend is shifting towards a mediation between two ways, exploiting the strengths of both: digital procedural generation and human unpredictability, digital perfection and analogue freedom, digital spreadability and analogue uniqueness.

A very good example of post-digital game is State of Play's game *Lumino City* (2014), a very particular puzzle game telling the story of Lumi, a young girl who follows a series of clues in order to save her grandfather.

This computer game features a perfect balance between digital and analogue. Its developers went beyond the hand-drawn video games mentioned before. The objects and scenario appearing in the game are completely hand-crafted. State of Play members built the entire set of the game out of paper, cardboard wood, some little lights and a custom set of motors. The crafting work and its digitization took 3 years: the team built a 3-m-high miniature city, photographed it, and turned it into a natural-feeling video game world. Although one of the reasons that pushed the developers to adopt this solution was of economical nature, the effect of warmth, the tangible feeling of authenticity, of materiality acquired by the overall experience is probably the main reason of the success of this game. The result of this experiment is a visual aesthetic that is both photoreal and dreamily cartoonesque, a graphic regime able to bridge between digital and analogue and to exploit the strength of both.

Cross-References

- ▶ Comic Arts in Games, Asset Production, and Rendering
- ▶ Indie Game

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Postproduction

▶ Virtual Reality Stereo Post-Conversion After Effects Workflow

Postproduction in Game Cinematics

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Synonyms

CG; Codec; Compressor/decompressor; Computer generated

Definition

For the purposes of this entry, *postproduction* refers to the creative editorial, color correction, and delivery aspects of video for game cinematic production.

Introduction

In order to help convey narrative or plot elements within a game, designers will often use the tried and tested methods of cinema, the visual language of which is familiar to most gamers.

The challenge is to ensure that the cinematic feels connected to the game world environment and supports the overall story. This does not necessarily mean it must match *aesthetically* with the game itself, but simply that it should feel integrated into the overall design.

By virtue of their linear nature, cinematics necessarily interrupt game play. This is opposed to narration, verbal character exposition, or other storytelling devices which exist as part of the game world. Nevertheless, cinematics can play an important role in scene setting by explaining key concepts of the game (tutorials, character history, scene setting, clues, etc.) in an easily digestible and engaging manner.

Sometimes a "hybrid" of game and cinematic sequence is created where a limited amount of user interaction is still permitted or segues are created to smooth the transition (Fig. 1).

Real Time Versus Non-real Time

The choice of whether to use real-time or pre-rendered "non-real-time" cinematics depends on a number of factors, including design considerations, hardware capabilities, or narrative demands. This decision must be weighed against the benefits and compromises inherent in both strategies. What follows is a summary of the two approaches and an overview of the process employed in both.

Non-Real Time (Pre-rendered)

In this approach, cinematics are played out as prerecorded full-screen movie files using either a proprietary or standard universal file format.

Since the movie is entirely self-contained, the designer can utilize a traditional production methodology. Visual style can be representative of the game world or incorporate live action. (Live action describes traditional filmmaking with a real camera in the real world.)

This approach provides the following advantages:

1. The postproduction process is not dissimilar to any traditional television/movie production and can utilize the same production pipelines. This includes acquisition (live action or CG), editing, color grading, and sound design.
2. It can exploit render technologies that are beyond the capabilities of the game engine or specific gaming hardware.
3. It is possible to utilize assets that are consistent with the game but with much higher detail. Examples might be improved visual effects, physics simulations (cloth, destruction), or elaborate facial animation.

Postproduction in Game Cinematics, Fig. 1 Examples of in-game cinematics from Crysis 3 (l) and Ryse (r). Crysis 3 cinematic is aesthetically similar to the game itself and connects directly to game play, whereas Ryse is more abstract, yet still serving the overall story

4. Overlays (such as Flash (Adobe FLASH, a vector-based graphics application)) can often be used in combination with movie playback to augment the cinematic with dynamically updated material.
5. The movie is consistent across all platforms and devices.
6. The content can be repurposed for trailers or other promotional materials (Fig. 2).

Compression and Codecs

It can be assumed that the output movie will be compressed quite heavily in order to fit within the game disk/download size requirements.

HD (high definition) and 3D movies can be quite large and it is often necessary to restrict the available storage space for them. As a consequence, there is a visual disparity between real-time and pre-rendered content – particularly if attempting direct continuity between them. Modern audiences can spot the switch.

The degree to which the cinematic will be affected depends ultimately on the compression type used. Most "off the shelf" compressors for in-game use are optimized for CG content and employ RLE (run length encoding) type paradigms. These work best with footage that has large areas of uniform color and luminance with low noise.

Visual artifacts can be evident as overall softness in the image, color banding, blockiness (particularly during shot changes), and pixilation. The problem is often exasperated by postproduction techniques such as:

1. Fast editing. Rapid changes in shots can lead to blockiness at edit points, especially if the direction of motion/shot content changes significantly. This can be mitigated somewhat if the compressor allows for key frame placement.

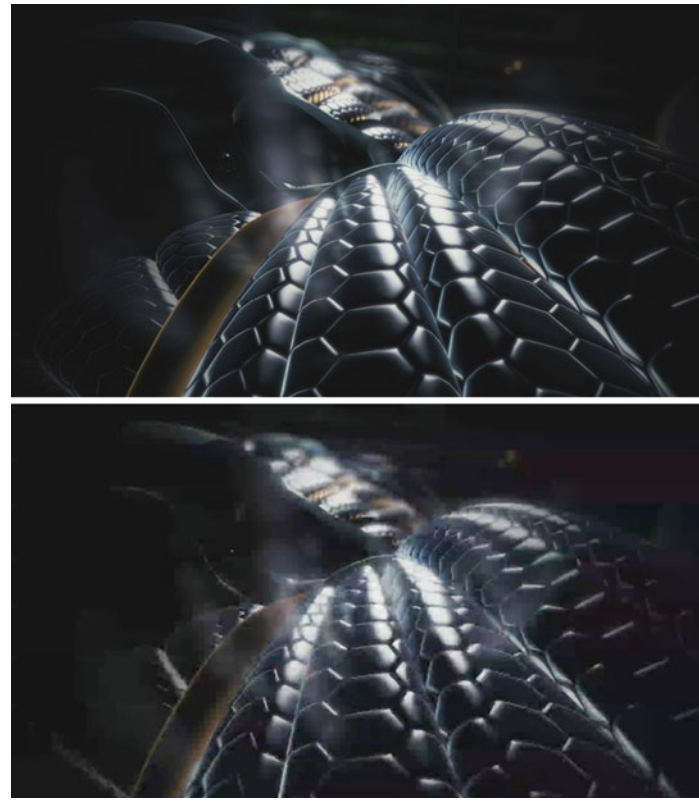
Postproduction in Game Cinematics, Fig. 2 Examples from Ryse of pre-rendered cinematics utilizing game assets

2. Dissolves/fades. These can place a high demand on the compressor since computationally there is often a big difference between the two shots. Transitioning from a night scene to daytime, for example, can be particularly demanding. Fades to/from black can look stepped or blocky in the dark areas of the transition.
3. Cinematic "treatment," such as artificial film scratches, film-burn, or noise. Although these techniques are very popular for lending a "film" style to shots, they also increase the demands placed on the compressor significantly. This is particularly true when working with compressor algorithms optimized for flat-shaded/CG-generated content that struggles with footage which contains live-action "organic" artifacts. Introducing artificial noise, for example, can undermine the regularity in a shot for which the compressor depends on to work effectively.
4. Soft masks/vignettes. These are often employed to create a stylized look to shots and/or used in combination with color grading effects. An issue can arise where the transition areas become blocky and blurry, particularly if the gradient is going to a solid color (Fig. 3).

In all cases, it is necessary to test sequences with the designated compressor and settings to see the results. Striking a balance between performance/space requirements/visual qualities can take time, but it is remarkable how subtle changes to content can make significant improvements to final results: a slight reduction in a lens flare, gamma adjustment, placement of a vignette, and duration of a fade.

Motion Graphics

It is common for motion graphics to be used in order to convey location on a map, character bios, and so on. Designers must be careful not to include very high levels of fine detail, small fonts, or subtle color/brightness graduations which can be lost after compression. Consideration must also be given to the fact that a consumer's display may not be able to resolve the same level of detail or be calibrated as well as that



Postproduction in Game Cinematics, Fig. 3 Extreme example of compression artifacts (amplified for this example). *Top* image is the original, *bottom* image after compression. Note corruption in dark areas (*red rectangle*), lens flare problems, overall loss of detail, gamma shift

of the designers. The "over scan" area of the picture must also be factored in, with sufficient room allocated to compensate for older CRT type displays.

Sometimes it may be more appropriate to use a vector-based renderer to display the motion graphics files directly, rather than include them compressed within movies. Such renderers are often used with HUD (heads-up display) elements (Fig. 4).

Mastering

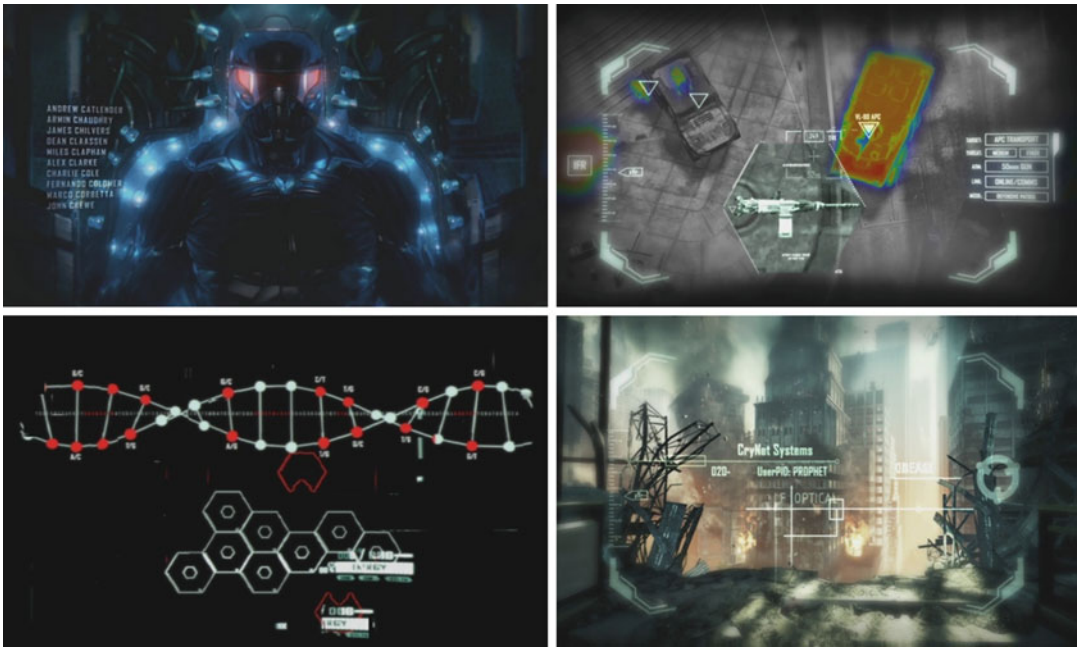
The intermediate and final mastering formats can also impact the final output quality. During all stages of production, it is important to use lossless compression strategies and maintain consistency in color profile/gamma. Any discrepancies can lead to issues with final compression and increase visual disparity between in-game and pre-rendered assets. Gamma and color issues can also occur if the operating space is not interpreted correctly between codecs.

Delivery

The question of delivery format is relevant to any production in today's online world. Playback devices could range from a smartphone LCD display to a theatrical cinema projector. Mitigating the effects of a variety of formats is a constant challenge, and this is particularly the case when working with game cinematics.

Since the movie will be delivered at a fixed frame size and frame rate, it needs to be established early on in production what the requirements will be.

Any changes by the user to the game resolution will also require the movie file to be adapted on the fly. The quality of the scalar will dictate final quality in such cases.



Postproduction in Game Cinematics, Fig. 4 Motion graphics examples from Crysis 2 with vector-based overlays applied to pre-rendered movies

Real-Time Cinematics

As performance capabilities of game devices have improved, designers are increasingly utilizing the in-game engine to render high-quality cinematics in real time.

This provides for several benefits over non-real time:

1. Image quality is consistent with the rest of the game and does not suffer from the compression issues inherent with movie files.
2. Frame size can be adapted on user requirements, rather than being fixed to final video resolution as required.
3. A seamless transition from game to cinematic can be achieved.
4. A degree of user interaction can be included as the cinematic plays out and can therefore feel more "integrated" into the game itself.
5. The cinematic can be adapted depending on the current game state (e.g., a customizable character, object locations, and environmental/time of day factors).
6. The data size footprint of the cinematic can be much lower than an equivalent HD movie, particularly if it utilizes existing game assets (Fig. 5).

However, there are certain factors which should be considered:

1. Each shot change requires not only the camera to be repositioned but also in-world assets, characters, and lighting to be adjusted too. This can lead to a noticeable redraw delay depending on complexity of the scene. This must be considered when designing the sequence.
2. The cinematic is generally restricted to assets that are created for the game environment. This limits the use of third-person perspectives, higher-quality meshes, complex physics simulation, or effects that would otherwise only be possible in pre-rendered sequences.
3. If specific assets are required for use in the cinematic, these need to be loaded and then unloaded from memory. This can result in

Postproduction in Game Cinematics, Fig. 5 Real-time scene setting in Crysis 3 (*top left*) and examples of first-person character exposition

noticeable delays or issues with memory allocation during a sequence.

4. Post effects such as lens flares, noise, film treatment, or masking can be very CPU intensive and restrict their use.

The production process requires careful management to ensure artists can work effectively and in collaboration with each other. For example, level design considerations could conflict with those of the cinematic designers or confine shot perspectives to certain angles. When dealing with dialogue scenes or exposition, the lack of a third-person character model (or a model intended for purposes other than direct viewing) can be problematic. Because of this, and in order to maintain a visual continuity, designers will often opt to shoot the cinematic from a first-person perspective and maintain this until the game resumes. The action therefore plays out more like a stage play, with the user themselves having some degree of control over the "editing."

When it comes to editing the cinematic in a more traditional sense, the tools tend to be those provided by the game engine and are generally not optimized for creating linear content. It is also problematic to interchange data between the engine and more established postproduction environments where seasoned filmmakers are more familiar. Extras loops of effort can be involved in translating between the two worlds.

However, the situation is improving gradually. One current example would be LUT (lookup table) files used in color correction, whereby dedicated grading software can be utilized and the results fed back into the game engine for matching. The importance of intuitive shot editing tools and/or the capability to exchange data with industry standard formats is also being realized.

It is also possible to use storyboarding, off-line edits, mock-ups, or pre-visualization prior to production in order to facilitate the process. Very often these mock-ups will be integrated into the game in some form to test their effectiveness and allow for amendments if necessary.

The aim of all these innovations is to allow the evolved disciplines of filmmaking to play a role in the game cinematic.

Whether real time or non-real time, the purpose of creative storytelling remains the same: to engage and entertain the audience.

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Potential of Augmented Reality for Intelligent Transportation Systems

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Synonyms

Augmented reality; Intelligent transportation systems; Network resource management; Vehicular ad hoc networks; Virtual reality

Definition

Augmented reality (AR) is usually regarded as a human-computer interface which enhances a human's perception of the real world by superimposing useful contextual information in real time (Ling 2017). Over the past few years, AR systems have made remarkable advances in several industries, including aerospace, automotive, robotics, health, military, education, marketing, social media and networking, tourism, gaming, etc. It is anticipated that the next revolutionary wave in industry would come in the shape of a significant dependence on AR devices and systems. In contrast, virtual reality (VR) is a computer-generated three-dimensional immersive experience which is displayed either on a computer display or via special stereoscopic displays, such as Facebook's *Oculus Rift* system.

Introduction and Background

Rapid advances in wireless communication technologies coupled with ongoing massive development in vehicular networking standards and innovations in computing, sensing, and analytics have paved the way for intelligent transportation systems (ITS) to develop rapidly in the near future. ITS provides a complete solution for the efficient and intelligent management of real-time traffic, wherein sensory data is collected from within the vehicles (i.e., via their onboard units) as well as data exchanged between the vehicles, between the vehicles and their supporting roadside infrastructure/network, among the vehicles and vulnerable pedestrians – subsequently paving the way for the realization of the futuristic Internet of Vehicles (IoVs) (Yang et al. 2017). The traditional intent of an ITS system is to detect, monitor, control, and subsequently reduce traffic congestion based on a real-time analysis of the data pertinent to certain patterns of the road traffic, including traffic density at a geographical area of interest, precise velocity of vehicles, current and predicted travelling trajectories and times, etc.

However, merely relying on an ITS framework is not an optimal solution. In case of dense traffic environments, where communication broadcasts from hundreds of thousands of vehicles could potentially choke the entire network (and so could lead to fatal accidents in the case of autonomous vehicles that depend on reliable communications for their operational safety), a fall back to the traditional decentralized vehicular ad hoc network (VANET) approach becomes necessary. It is therefore of critical importance to enhance the situational awareness of vehicular drivers so as to

enable them to make quick but well-founded manual decisions in such safety-critical situations. Modern-day vehicles that utilize sophisticated cameras and radars to project front/rear images and to detect obstacles, respectively, need to present this contextual information to drivers in ways that inform and do not distract them. Conventional displays mounted on dashboards or middle consoles divert the attention of drivers from the primary task of driving. Also, contextual information in these displays is not usually superimposed, and if superimposed, it is presented in a higher degree of detail which not only increases the cognitive load of the drivers but also adds to the overall delay of responding to an unforeseen event. This is where AR comes into play, which, unlike its predecessor (i.e., virtual reality), *enhances* a driver's perception by superimposing useful real-world context in minimal detail in a driver's line of sight.

AR is realized by executing the following four basic tasks (Glockner et al. 2014):

Scene Capture. In the first stage, reality is captured either by employing a video-capturing device (camera) or a see-through device (head-mounted display).

Scene Identification. Once the reality has been captured, it should be scanned in order to identify a particular position where the respective virtual content should be embedded. This position may be identified with virtual tags (markers) or tracking technologies such as sensors, laser, infrared, or GPS.

Scene Processing. Once the captured scene is completely identified, its corresponding virtual information needs to be requested from a database via the Internet. The associated information, with up to the minute detail, is accumulated and subsequently processed in the cloud (either at the network edge or remote cloud) with sufficient compute resources to filter the minimal useful virtual content.

Scene Visualization. Lastly, the AR system generates an amalgamated image of the real scene with the superimposed virtual content, which is subsequently displayed in the driver's visual field.

AR is regarded as one of the several key technology enablers which could set up the conditions for a "perfect technological storm" in the coming decades, as illustrated in Fig. 1. It is interesting to note that the video-processing aspects of AR, in convergence with some of these other technology enablers, could meet many of the more difficult requirements of future autonomous vehicles. The widespread adoption of such vehicles would eventually lead to the realization of next-generation ITS frameworks and smart cities. Apart from the automotive sector, AR is anticipated to revolutionize many industries, including manufacturing, healthcare, education, logistics, architecture, military, gamification, and data centers (Uchida et al. 2017).

AR requires specialized hardware and software, and the development and implementation of this software relies on a highly capable, state-of-the-art hardware and networking. These have been the subject of ongoing research and development by scientists and engineers in the domains of microprocessors, sensors, display systems, battery life, high-resolution cameras, mobile internet speeds, and more. At the time of writing (2018), the "industry best practices" in terms of available AR hardware include handheld devices (*smart phones and tablets*), stationary AR systems (*AR wardrobes*), spatial AR systems, head-mounted displays (*Oculus Rift*), smart glasses, smart contact lenses, etc.

The Need and Potential of Augmented Reality for ITS

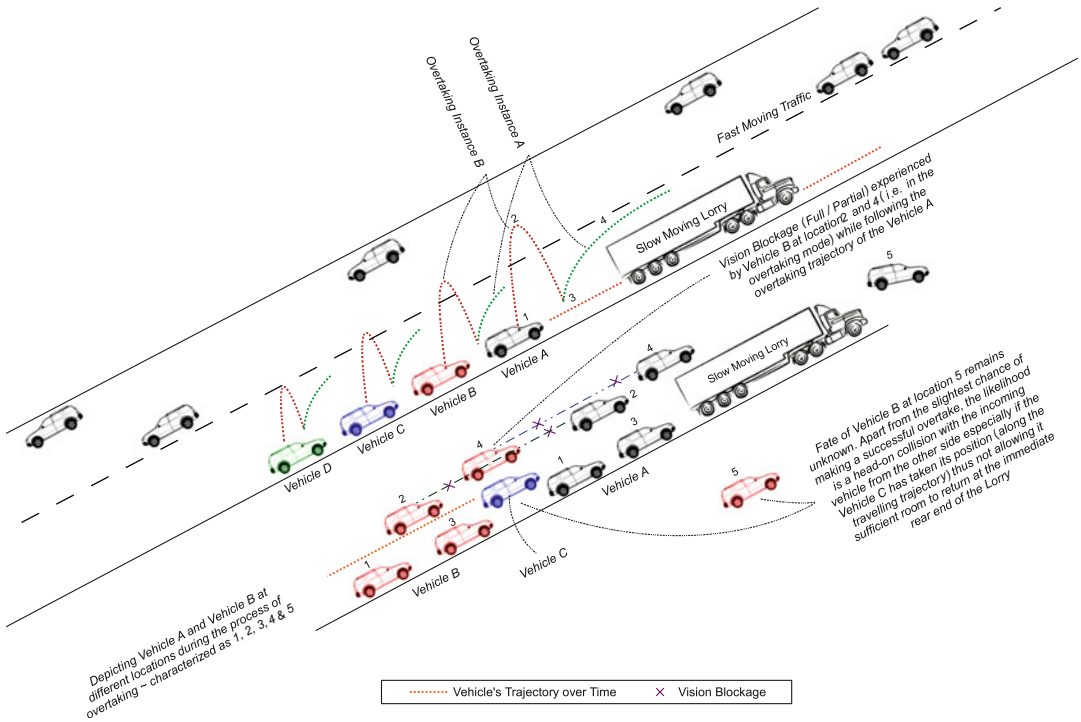
Since the advent of automobiles as early as the mid-nineteenth century, each vehicle has been driven by a single human driver, according to his/her requirements, preferences, etc. However, with massive increases in vehicular traffic leading to road congestion and soaring energy costs, the potential benefits of cooperative driving, especially "*platooning*" has received attention.

M2M Communication (Embedded Sensors in Machines and Products)
Big Data & Analytics (Understand Vast Pool of Data in Real-time)
Network Ubiquity (Driving Intelligence Everywhere)
Augmented Reality (Complementary Information to Real-time Data)
Key Technology Enablers
Mobility (Driving Information to point of need)
Social Technologies (To Drive Collaboration)
Open Standards (Enabling Integration)
Mature & Secure Cloud (Balancing Central & Local Data)
3D Printing (Make-To-Individual Manufacturing a Reality)

Potential of Augmented Reality for Intelligent Transportation Systems, Fig. 1 Powering technological innovation – key technology enablers for Industry 4.0

Vehicle platooning aims to significantly reduce the inter-vehicular distances relative to that recommended for manual driving. This is achieved by (1) making driving more predictable by sharing common objectives rather than having individual drivers make uncoordinated decisions and (2) by partially or fully automating common driving tasks, offering faster reaction times than could be achieved by unassisted human drivers. Hence, the smaller the space between vehicles becomes, the more vehicles can be packed in that (finite) road space, thereby increasing road capacity. A supplementary benefit of closer vehicle placement is that it can lead to reduced aerodynamic drag, thereby increasing energy efficiency (Qiu et al. 2017).

Nevertheless, significantly reducing inter-vehicular distances also needs to be safe. This aspect (safety) has been studied in the ITS research literature and highlighted as one of the main challenges hindering the full realization of ITS. Accordingly, significant technological advances in autonomous vehicles and advanced driver assistance systems (ADAS) have been made over the years that have completely altered our perception of transportation safety. Google, Delphi, Tesla, Mercedes-Benz, Porsche, Nissan, and Bosch (to just name a few) are already testing safely driven autonomous vehicles and numerous intelligent ADAS functions, such as lane departure warning, collision warning, autonomous emergency braking, and adaptive cruise control. Some of these are now being offered as options in production vehicles (Kaur and Sobti 2017). Nevertheless, in spite of these technological developments, road accidents continue to happen due to human factors such as misjudgments and erratic human behavior. Research studies (Rameau et al. 2016; Abdi and Meddeb 2018) have analyzed the causes of fatal traffic accidents. Head-on collision as a result of overtaking at high speed is one of the major causes of road fatalities


Overtaking Instance B
Overtaking Instance A
Fast Moving Traffic
Slow Moving Lorry
Vision Blockage (Full / Partial) experienced by Vehicle B at location 2 and 4 (i.e. in the overtaking mode) while following the overtaking trajectory of the Vehicle A
Vehicle A
Vehicle B
Vehicle C
Vehicle D
Slow Moving Lorry
Fate of Vehicle B at location 5 remains unknown. Apart from the slightest chance of making a successful overtake, the likelihood is a head-on collision with the incoming vehicle from the other side especially if the Vehicle C has taken its position (along the travelling trajectory) thus not allowing it sufficient room to return at the immediate rear end of the Lorry
Depicting Vehicle A and Vehicle B at different locations during the process of overtaking – characterized as 1, 2, 3, 4 & 5
Vehicle's Trajectory over Time
Vision Blockage

Potential of Augmented Reality for Intelligent Transportation Systems, Fig. 2 Depicting human behavior in overtaking scenarios – conventional driving scenario

and generally occurs due to occlusion (blocking) of the overtaking driver's field of view, as depicted in Fig. 2. AR could be extremely beneficial here by enabling the overtaking driver to "see through" the slow-moving lorry to the vehicles immediately preceding it and thus make safer overtaking decisions.

Such enhanced situational awareness is highly valuable, given all the in-vehicle secondary tasks assigned to the driver, from adjusting the temperature and ventilation to conversing with other passengers. In the autonomous cars of the future, distractions will be even greater: infotainment for listening to music, making and/or receiving calls, reading and/or sending emails, etc. Also, the level of attention required while driving varies according to the conditions, as driving in dense fog or heavy rain and snow usually requires a higher degree of risk awareness compared to driving on a sunny day with a clear view. Thus, limited visibility and driver distractions pose grave threats to situational awareness and can cause serious road accidents. Also, providing a driver with excessive data results in higher cognitive workloads and weaker driving performance (Contreras et al. 2017). Furthermore, while current sophisticated driving systems can support drivers by providing detailed information, the presentation systems generally require drivers to divert their attention to displays mounted on dashboards or middle consoles. This is where AR comes into play by rendering *critically important* information in a driver's line of sight, thereby decreasing both cognitive workload and distraction while driving. However, it is pertinent to note that the information being displayed should be carefully chosen. It should be derived from a wide variety of onboard sensors, enhanced with data from the roadside and other vehicles, shared over wireless links, and intelligently extracted with sufficient but not excessive detail. Remote data can be shared using vehicle-to-vehicle (V2V), vehicle-to-infrastructure/network (V2I/N), and vehicle-to-pedestrian (V2P) communication.

Potential of Augmented Reality for Intelligent Transportation Systems, Table 1 Example link layer parameters for V2X services

Scenarios	Effective range (meters)	Absolute speed of UE (km/h)	Relative speed b/w two UEs (km/h)	Tolerable latency (ms)
Major roads/suburban	200	50	100	100
Motorway/freeway	320	160	280	100
Autobahn	320	280	280	100
Non-line of sight/ urban	150	50	100	100
Urban intersections	50	50	100	100
Shopping area/campus	50	30	30	100
Imminent crashes	20	80	160	20

Source: 3GPP Technical Report 22.885 v14.0.0 (3GPP 2015)
It should be noted that there are various parameters involved in these scenarios, i.e., physical (relative speed, effective range), incidental (line-of-sight occlusion), and service-related (maximum tolerable latency). These parameters can be derived from the principle that there should be more than 95% probability that a vehicle has received at least one V2X message from two consecutive V2X messages notifying it of any impending incident.

Also, it is essential to display this information with very low latency: the maximum tolerable delay in the case of safety-critical vehicular applications is in the range of 20–100 ms as depicted in Table 1.

The Need for Intelligent Network Resource Management in ITS

The low-latency requirements of safety-critical vehicular applications increase the demand for intelligent and efficient network resource management, because vehicular AR applications have numerous parts that need to be managed. At present, the number of sensors on vehicles is approximately 100, and this number is expected to double by 2020. According to Intel estimates, autonomous vehicles are anticipated to generate and consume 5 TB of data for every hour of driving, and the primary reason for this appetite is the growth of onboard sensors with automotive cameras and radars alone generating 20–40 Mbps and 100 kbps of data, respectively (Nelson 2018). ITS networks also need to support additional data streams such as that generated by humans (vehicular users and roadside pedestrians). As estimated, vehicular users on average consume around 650 Mbps of videos, chat, and Internet usage per day, and this is anticipated to increase to 1.5 Gbps per day by 2020. The third source of data arises from certain crowd-sourced traffic platforms, such as Google Waze. Processing such big data arising from hundreds of thousands of vehicles requires extremely high computational power and intelligent machine learning algorithms to extract critically important information to be rendered for each driver.

Furthermore, unlike traditional networks, VANETs are highly distributed in nature, and owing to the high mobility of vehicles, the geospatial environmental context also changes rapidly, leading to a dynamically changing network topology. Traditional networking architectures were designed for more static contexts and are thus unable to cater for such challenges. Consequently, there has been a shift toward a more agile approach to ensure reprogrammability, scalability, flexibility, and elasticity. The emerging and promising paradigm of software-defined networking (SDN) together with edge-based computing can help to meet these challenges. SDN decouples the data plane from the control plane, and network intelligence is passed on to a logically centralized controller that is responsible for automating and orchestrating the network operations. Edge-based computing brings network resources, i.e., both compute and storage, nearer to the edge and proves extremely useful when caching frequently requested safety-

critical and non-safety (i.e., infotainment) applications and services, thereby reducing network delay by mitigating excessive network management overhead.

Conclusion

In most countries, the use of private motor vehicles has been on the rise, as consumers are drawn to the flexibility and convenience of such vehicles. Given associated trends such as increasing urbanization with the potential for increasing road congestion, the need for safer urban road environments has become more acute. Thus, the management of urban traffic demands a balance between throughput, safety, efficiency, and sustainability. Private motor vehicles need to share the roads with other modes of transport (i.e., public transport, bicycles, and pedestrians); this also adds to the complexity. Every road accident is one too many, especially when it results in severe injuries or the loss of human life. According to one estimate (Oh et al. 2016), more than 80% of road accidents worldwide happen due to the negligence of drivers or other human errors. Though there have been many sophisticated road safety technologies introduced over the past few years to enhance road safety, many of them resulted in distraction or cognitive overload for the drivers concerned. There is only a limited amount of visual stimuli to which drivers can attend, understand, and react without taking their eyes off the road, and it is essential to present drivers with only critical contextual information in minimal detail within their line of sight so that the right decisions can be made at the right time. This manuscript outlines the significance and need of AR in general and especially for the ITS domain and indicated some of the networking requirements necessary for its successful realization. Nevertheless, there are still many practical challenges, i.e., interpreting digital data, deriving meaningful graphics, and subsequently scaling it, without information loss, to suit the perspective of an individual's visual field, ensuring precise low-latency tracking and monitoring, developing seamless optical displays, etc. All of these need to be addressed so that AR for next-generation ITS platforms can achieve its full potential.

Cross-References

- ▶ Augmented Reality Entertainment: Taking Gaming Out of the Box
- ▶ Augmented Reality for Maintenance
- ▶ History of Virtual Reality
- ▶ Interaction with Mobile Augmented Reality Environments

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Preference Modeling

► Game Player Modeling

Prerendered Graphics

► Resident Evil 2, History of

Presence and Immersion in Virtual Reality

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Synonyms

Telepresence; Virtual presence

Definitions

Immersion is user's engagement with a VR (virtual reality) system that results with being in a flow state. Immersion to VR systems mainly depends on sensory immersion, which is defined as "the degree which the range of sensory channel is engaged by the virtual simulation" (Kim and Biocca 2018).

Presence within the context of virtual reality is defined as one's sense of being in the virtual world. The illusion is perceptual but not cognitive, as the perceptual system identifies the events and objects and the brain-body system automatically reacts to the changes in the environment, while cognitive system slowly responds with a conclusion of what the person experiences is an illusion (Slater 2018).

Even the VR professionals may mistakenly use the terms "presence" and "immersion" interchangeably; immersion stands for the objective level of sensory fidelity provided by a VR system (Slater 2003), whereas presence is the subjective psychological response of a user experiencing a VR system.

Conceptualizations, Discussions, and Evaluation

Immersion

Immersion is a controversial term due to multidisciplinary adoption of the term by researchers in the fields of virtual reality, narrative, and digital games. Even in the VR literature, there are conflicting definitions of immersion. Early studies (see Nash et al. 2000) focus on the immersion as a technical concept which point to "the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant" (Slater and Wilbur 1997). On the contrary, it is also defined as a "psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" (Witmer and Singer 1998). Boundary of the term was expanded

to cover interactions with non-VR computer systems such as desktop systems and even non-technologically mediated interactions such as storytelling (Brooks 2003). Despite the focus of his work was narrative immersion, Brooks (2003) also emphasizes on sensory immersion, suggesting that "sights and sounds by immersive media can cause a strong visceral and cognitive belief in what is experienced" and "virtual reality environments (VRE), or immersive environments, are so called because the participant is sensually immersed or surrounded by computer-controlled media." Even he broadens the term to cover the mental and emotional engagement of the participant, he still refers to the physical aspect of immersion. Baños et al. (2004) make a distinction between the media form (e.g., the extent of sensory information presented, the degrees of control that users have over positioning their sensors within the environment, users' ability to modify aspects of the environment) and media content such as objects, actors, and events represented by the medium. It is possible to name these two aspects of medium as sensory and narrative. Brown and Cairns (2004) mention game atmosphere that is composed of graphics, sound, and plot as a determinant of total immersion. They suggest that when gamers attend to sound as well as sight, they invest more attention and effort into the game, leading them to feel more immersed into the game. Clearly, these are also the sensory determinants of immersion. Ermi and Mäyrä (2005) propose a model for gameplay experience, based on sensory, imaginary, and challenge-based immersion. Sensory immersion is observed relying on audiovisual components of the game.

Recent studies in VR (e.g., Diemer et al. 2015) embrace the definition of Slater and Wilbur (1997), regarding immersion as "as a quality of the system's technology, an objective measure of the extent to which the system presents a vivid virtual environment while shutting out physical reality." Considering the subjective nature of presence, Diemer et al. (2015) propose "an interoceptive attribution model of presence," where immersion including interactivity is defined as system factor and perception and information provided by the VE is defined as the content. Because of "immersion and the degree of arousal they feel," "users make a judgment of the degree of presence they feel in VR."

A Framework for Defining Presence

As an essential component of VR experience, there is an agreement on three common features of presence: (1) presence requires involvement into the virtual environment; hence, the effectiveness of VEs is linked to the sense of presence reported by users; (2) presence is defined as a subjective experience; and (3) presence is a multidimensional construct (Gaggioli et al. 2003a).

In the early 1990s, at the time that VR technologies were evolving into consumer-level products, researchers also concentrated on "defining the virtual reality in terms of human experience rather than technological hardware" (Steuer 1992), and the concept of (virtual) presence became a subject of scholarly interest as a dependent measure of individual experience in VR. According to Biocca and Delaney (1995), VR systems may had already crossed a "psychological threshold, a point at which our perceptual systems are so immersed in the simulation that the user already begins to feel some of the sense of 'being there,' the early flushes of a powerful presence." This human experience-oriented approach to VR ignited a still ongoing debate about the definition of "presence" (Barfield 2016).

The concept of presence became a VR-related topic since Sheridan (1992) suggested that it could be applied to a virtual environment as a special case of teleoperation in which the remote site is virtual rather than real. Using the term as "virtual presence," he described the concept as "sense of being physically present with visual, auditory, or force displays generated by a computer."

One of the most referred definitions of presence is simply articulated as "sense of being there," sense of being in one place or environment (i.e., a virtual environment) even when one is physically situated in another (Minsky 1980; Heeter 1992; Witmer and Singer 1998). Although the term is simply articulated as "presence," the VR-related research is mainly focused on "spatial presence," a technology-mediated experience

which is different from "natural" or "proximal" presence that human beings are subjected to in their real-world experience.

On the other hand, the phenomenon of presence is not specific to VE's and teleoperation systems. Scholars in communication studies and psychology explored the concept, and they provided divergent and overlapping definitions. Lombard and Jones (2015) suggested a framework to organize the efforts to define the concept of presence in different disciplines. According to their framework, presence in VR can be defined as a technology-mediated phenomenon and focuses on subjective experience of the person that is triggered by external stimuli that leads to an inaccurate perception of technology involvement. The primary interests of definitions within this scope could be spatial presence, social presence, engagement, and realism.

Presence as a Technology-Mediated Phenomenon

The first layer of Lombard and Jones' framework (2015) organizes the presence definitions by questioning the involvement of technology, denoting that some definitions explicitly exclude the technology while others state that presence may occur with or without technology, as the third subset of definitions explicitly involve technology. A detailed description of technology was given as "a machine, device, or another application of human industrial arts" that are not only limited to traditional and emerging electronic media, traditional print media, and traditional arts but also include "technologies used to correct deficiencies in 'normal' perception of the physical world (e.g., eyeglasses and hearing-aids) as well as those designed to augment or enhance perception" (International Society for Presence Research 2000). Furthermore, since the current technologies depend on providing stimuli for sensory organs, future technologies that may directly stimulate the human neural processing system were considered within the definition of technology related with presence. Lombard and Jones (2015) preferred the term "telepresence" for historical reasons, to point out technology-mediated presence. The primary condition to define presence within the context of VR is to emphasize mediation of technology. Steuer (1992) denoted that "telepresence is defined as the experience of presence in an environment by means of a communication medium." Witmer and Singer (1998) emphasized mediated nature of telepresence as "the subjective experience of being in one place or environment, even when one is physically situated in another." Biocca et al. (2003) refer to "spatial cues and the mental models of mediated spaces" which create "the illusion of place." Waterworth and Waterworth (2003) define "electronically mediated presence" as a perceptual illusion. All these definitions emphasize the mediated nature of presence in VR.

Presence as a Subjective Property of Person

On the second layer, Lombard and Jones' (2015) framework "concerns whether the phenomenon being defined is an objective property of a mode of communication, technology, person, object or entity, or a subjective property of a person." Having an objective perspective on mode of communication, Zhao (2003) defines mediated presence as "a form of human co-location" where people "are located in each other's electronic proximity rather than physical proximity." Floridi (2005) also has an objective perspective while he defines presence as a property of entity depending on entity being located in a local or remote space of observation and being observed in level of abstraction. Although these definitions emphasize the objective nature of mediated presence, several authors denoted the subjective nature of presence as an "experience" or "perception" of an individual calling presence "a psychological phenomenon" (Sas and O'Hare 2003), an "experience" (Steuer 1992), a "subjective feeling or mental state" (Sheridan 1992), and "a psychological state" (Lee 2004). Suggesting a focus on users' subjective experience rather than how the technology mimics the virtual world, Heeter (1992) offered to investigate presence as subjective personal presence, social presence, and environmental presence. These definitions focus on the subjective nature of presence in VR.

Several studies focus on effects of the individual characteristics and the personality traits on presence (see Galloso et al. 2016; Ling et al. 2013), providing further evidence that interpersonal differences affect the "ability to experience the VRE as real and vivid" (Wallach et al. 2009).

Presence as an Experience Triggered by External Stimuli

The third layer of Lombard and Jones' (2015) framework focuses on "source of the stimuli," which can only be explored in terms of presence as "subjective property of a person." Some definitions of presence take the source of stimuli only as external as "impingements on the senses from the physical world outside the body" (Lombard and Jones 2015), as "experience of one's physical environment" (Steuer 1992), as "the feeling of being located in a perceptible external world around the self" (Lombard and Jones 2015), "as the feeling a conscious organism experiences when immersed in a concrete external world" (Waterworth and Waterworth 2003), or as an experience that is "defined as a person's observation of and/or interaction with objects, entities, and/or events in her/his environment" (International Society for Presence Research 2000). Some authors suggest that the stimuli triggering the experience could either be external or internal, as in Biocca's (2003) model, in which presence may occur between the three poles: physical space, virtual space, and internal imagery space.

Presence as an Inaccurate Perception of Technology Involved

The fourth layer of Lombard and Jones' (2015) framework explore the accuracy in perception of technology. For presence in VR, users have an inaccurate perception of technology. They perceive that technology is not involved in the experience, although it is. There is a "perceptual illusion of non-mediation," suggesting that a user experiences presence when he fails to perceive or acknowledge that the environment is being presented to him through some type of media such as television or HMDs (Lombard and Ditton 1997). In virtual presence "the stimuli of a proximal environment created by a presence medium in simulation of the intended environment, which is either inaccessible or nonexistent, press upon the sense organs of the perceiver" and "sense of presence is the subjective experience of being present in an intended environment outside one's body" (Zhao 2002).

Primary Interests of Defining Presence in VR: Spatial Presence, Social Presence, Engagement, and Realism

At this point, Lombard and Jones's framework suggest several aspects of primary interest for the presence phenomenon as the fifth layer of their definition categories. When the primary interest is the physical environment, the definition is related to spatial presence, that can be described as "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer and Singer 1998) or "phenomenal sense of 'being there' including automatic responses to spatial cues and the mental models of mediated spaces that create the illusion of place" (Biocca et al. 2003). Some definitions of presence have a primary interest in engagement, as in Jacobson (2002) stating that "presence is the experience of being engaged by the representations of a virtual world" which "often involves a strong connection with the content and/or form of an experience" (Lombard and Jones 2015) and related to distinct but closely related concepts such as attention, involvement, flow, absorption, and (perceived) immersion (Schubert et al. 2001; Witmer and Singer 1998). Realism is another aspect of presence that is of interest, focusing on the correspondence between a technology-mediated experience and a similar experience not mediated by technology. Slater (2003) defined presence with an emphasis on realism, as "response to a given level of immersion (and it only really makes sense when there are two competing systems – one typically the real world, and the other the technology delivering a given immersive system)," while Lee (2004) stated that presence is "a psychological state in which virtual

(para-authentic or artificial) objects are experienced as actual objects in either sensory or non-sensory ways." Zahorik and Jenison (1998) emphasize on the successfully supported actions within the environment and suggest that when "the environmental response is perceived as lawful, that is, commensurate with the response that would be made by the real-world environment in which our perceptual systems have evolved, then the action is said to successfully support our expectations." These definitions focus on the perceptual realism. On the other hand, Lombard and Ditton (1997) define the phenomenon as "the extent to which a media portrayal is [perceived as being] plausible or 'true to life' in that it reflects events that do or could occur in the non-mediated world" and suggest that the plausibility is not limited to perceptual realism but also refers to the narrative being "true to life," which is social realism. Social presence is related to social entities, and definitions generally involve people and/or electronic representations of people, such as "the feeling of being socially present with another person at a remote location" (Sallnäs et al. 2000) or "mutual interaction with a perceived entity refers to the degree of initial awareness, allocated attention, the capacity for both content and affective comprehension, and the capacity for both affective and behavioral interdependence with said entity" (Harms and Biocca 2004). Their study also focuses on interpersonal interactions whereas the given description refers to an entity that can be non-human, such as an NPC (non-person character) or an agent with artificial intelligence.

Measuring Presence

Laarni et al. (2015) classified the methods of measuring presence as objective and subjective methods and criticized these methods. Subjective methods are post-test rating scales in form of questionnaires, continuous subjective presence assessment techniques which employ a slider or counter, psychophysical methods such as magnitude estimation and paired comparisons which produce interval scaled data, and qualitative methods such as interviews, focus groups, think-aloud sessions, ethnographic techniques, experience sampling method, and repertory grid analysis. Objective measures are behavioral, performance-based, and physiological measures of presence.

Subjective Measures

Post-test rating scales hold an important place in the evaluation of presence due to the subjective nature of phenomenon (Insko 2003). Within the early efforts, several remarkable attempts are Slater-Usoh-Steed (SUS) (Slater et al. 1995) questionnaire and Kim and Biocca's (1997) questionnaire. Hendrix and Barfield's (1996) efforts lead to a questionnaire that assesses presence and realism.

Further studies investigate the concept of presence as a multidimensional construct, as Witmer and Singer's (1998) Presence Questionnaire (PQ), which mainly investigates several attributes of VEs that could influence the sense of presence. PQ pairs up with ITQ (Immersive Tendencies Questionnaire) which measure differences in the tendencies of individuals to experience presence. ITQ evaluates users' tendency to become involved in activities, maintain focus on current activities, and play video games as three dimensions, while PQ evaluates the degree that VE provided using items related with involvement/control, naturalness, and fidelity of sensory modalities in terms of resolution, interface quality, auditory, and haptic feedback. Although it is expected that PQ and ITQ scores would always be positively correlated as revealed in Witmer and Singer's original work since a person's tendency to be immersed in a VE would lead to sense of presence, evidence from later studies are mixed. Thornson et al. (2009) developed the "Tendency Toward Presence Inventory" with an approach like ITQ, but their focus is "solely on the individual difference predictors of the tendency to experience presence and not on the environmental factors."

Sas and O'Hare (2003) suggested to measure presence through two primary consciousness dimensions of "being in the VE" and "not being in the VE" with a third dimension of reflective

consciousness that represents awareness of self and outside world. Biocca et al. (2001) attempted to measure presence with 18 items in 3 dimensions: spatial presence, tactile engagement, and sensory presence.

I-Group Presence Questionnaire (IPQ) (Schubert et al. 2001) was developed employing several items from previous research among original items suggested by authors. The 16-item scale evaluated presence in terms of spatial presence, involvement, and judgment of realness.

Independent Television Commission-Sense of Presence Inventory (ITC-SOPI) (Lessiter et al. 2001) measures presence with 44 items using 4 subscales: sense of physical space, engagement, ecological validity, and negative effects. The respondents in the original study were exposed to 2D and 3D IMAX movies, a projected movie recorded on VHS, a short video on a 28-inch TV, and a console computer game. ITC-SOPI was applied in VR studies later (e.g., Baños et al. 2004; Baus and Bouchard 2017).

MEC-SPQ (Project Presence: Measurement, Effects, Conditions-Spatial Presence Questionnaire) (Wirth et al. 2007) has 9 dimensions conceptualized within two levels: Spatial Situation Model as the first level and Spatial Presence as the second level. Besides media factors affecting both levels, Spatial Situation Model dimension is constructed through the process factor named Attention/Allocation. A trait-like dimension called Spatial Visual Imagery also contributes to the construction of the Spatial Situation Model dimension while the Attention/Allocation dimension is influenced by another user trait: Domain-specific Interest dimension.

On the second level, Spatial Presence is constructed depending on the Spatial Situation Model. At this level, dimensons regarding to state and actions of user, Higher Level of Involvement and Suspension of Disbelief influences the construction of Spatial Presence. Another user trait dimension, Absorption induces Higher Level of Involvement and Suspension of Disbelief dimensions. Spatial Presence is measured within two dimensions: Self-Location and Possible Actions (Laarni et al. 2015). Each of these subscales can be applied as four-item, six-item, or eight-item versions. Spatial Experience Scale (SPES) (Hartmann et al. 2015) is a short-form spatial presence scale based on the "self-location" and "possible actions" subscales conceptualized in MEC-SPQ. Pictorial Presence Self-Assessment Manikin (Weibel et al. 2015) uses six of the dimensions conceptualized in MEC-SPQ to measure presence using visual material instead of verbal items.

The Tempe Presence Inventory (TPI) (Lombard et al. 2009) has 42 items within the subscales related with social presence which are parasocial interaction, passive interpersonal presence, active interpersonal presence, social richness, and social realism besides 3 subscales of spatial presence, engagement (mental immersion), and perceptual realism.

Suggesting that there are temporal variations during the exposure to a VE, several studies used a handheld slider controlled by participants to indicate their level of presence continuously during the immersion (see Wissmath et al. 2011). Slater and Steed (2000) used a click-counter that participants use when they feel that they have switched from virtual environment to real world, counted as "breaks in presence." Although these methods aim to be unobtrusive, they require users' attention to provide a continuous measurement during the experiment.

Magnitude estimation and paired comparison were offered for measurement of presence (Stanney and Salvendy 1998), but these methods were not directly to measure presence in virtual reality yet, except magnitude estimation used for evaluating "conflict perceived" between haptic and visual feedback of a system (Kuschel et al. 2007).

Some other subjective qualitative methods that had been used in presence research were interviews, think-aloud sessions (Turner et al. 2003), experience sampling (Gaggioli et al. 2003b), repertory grid analysis (Steed and McDonnell 2003), focus groups (Heeter 1992; Freeman and Avons 2000), and ethnographic observations (McGreevy 1994).

Objective Measures

Objective measures of presence "are difficult to implement for virtual presence" (Nash et al. 2000) due to subjective nature of the phenomenon.

Adopting a behavioral perspective along with a subjective approach, Slater et al. (2009) suggested that "presence refers to how realistically participants respond to the environment as well as their subjective sense of being in the place depicted by the VE." One of the behavioral measures used in presence research is direct observation of adaptive behaviors evoked by virtual dangers (Insko 2003; Lepecq et al. 2009; Slater et al. 1995). Some of these studies provided evidence that users' adaptational behaviors are correlated with the subjective measurements of presence, but it should be noted that only highly immersive VEs evoked these adaptational behaviors. There is also counter-evidence that fidelity of the VE does not affect the performance of users (Vignais et al. 2010) so that presence and performance are not likely to be correlated. Body movements and postural sway were also investigated as indicators of presence (e.g., Slater and Steed 2000; Stanney et al. 2002). Guerraz and Bronstein (2008) verified the relationship between visually induced illusion of self-motion and automatic postural adjustments but revealed that postural sways occur prior to conscious sense of vection. Attention-based measures of presence explore the users' awareness of stimuli in the real-world ambience, while they were immersed in a virtual environment (e.g., Slater et al. 1995).

Performance measures of presence are based on the "assumption that users perform better in a highly immersive VE," but the link between performance and presence is questionable. Frameworks such as VEPAB (Virtual Environment Performance Assessment Battery) (Lampton et al. 1994) and VRMAT (Virtual Reality Manipulation Assessment Testbed) (Poupyrev et al. 1997) were suggested to measure user performance in VEs. Nash et al. (2000) proposed several measures of performance that can be bridged to presence. Stanney et al. (2002) denoted that users who reported higher sense of presence were more efficient and effective in completing tasks. Youngblut and Huie (2003) found a positive correlation between the learning of mission procedures and presence. On the contrary, recent studies (see Cooper et al. 2018) report negative or insignificant correlation between performance measures and presence.

Presence is associated with eye-related (e.g., Jordan and Slater 2009), brain-related (see Clemente et al. 2014), heart-related (Egan et al. 2016; Meehan et al. 2005), and psychophysiological measures as well as physiological indicators of emotional response such as electrodermal activity (EDA) (Meehan et al. 2005) and muscular responses measured via electromyography (Antley and Slater 2011; see Kivikangas et al. 2011).

Cross-References

- ▶ Cognitive Psychology Applied to User Experience in Video Games
- ▶ Everyday Virtual Reality
- ▶ Game Design and Emotions: Analysis Models
- ▶ Immersive Auralization Using Headphones
- ▶ Immersive Technologies for Medical Education
- ▶ Immersive Virtual Reality Serious Games
- ▶ Social Virtual Reality
- ▶ Sonic Interactions in Virtual Environments
- ▶ Spatial Perception in Virtual Environments
- ▶ User-Centered Design and Evaluation Methodology for Virtual Environments

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Preserving the Collective Memory and Re-creating Identity Through Animation

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Synonyms

Animation; Cultural identity; Memory; Self narrative

Definitions

Narrative identity	It is a person's internalized and evolving life story, integrating the reconstructed past and imagined future to provide life with some degree of unity and purpose.
The self	The self is an *experience*, not a conception. We can formulate the experience, more or less, in a conception; *but it is an experience*.
Collective memory	Collective memories are shared representations of a group's past based on a common identity. They are shaped by, and transmitted through, narratives.
Inquiry-based learning	Inquiry-based learning is often described as a cycle or a spiral, in which there are stages of question formulation, investigation, creation of a solution or an appropriate response, discussion, and reflection in connection with results.

Introduction

> *Knowing others is wisdom. Knowing the self is enlightenment. Mastering others requires force. Mastering the self requires strength*. Lao Tzu, (Tao Te Ching)

Philosophy has always been in charge of questioning great dilemmas of the human psyche and its existence, leaving to sciences the body's affairs. Aristotle, Nietzsche, C. Jung, and William James, among others, have tried to define the essence of the self; Roberto Assagioli – father of Psychosynthesis (2019), the psychology of the Self – defined it as an experience, which happens through introspection in an environment of empathy and love (Firman and Gila 2007). Working with animation aids to create such an environment, a socio-emotional learning space to work movies as open dialogs, an opportunity for self-introspection a research identity process (Moen 2006) through character design and animation. Without entering into a deep Cartesian or metaphysical debate about identity, we are closer to gain a better understanding of the self and what consciousness might be. We, our self, build reality from what we have learned, through our senses, making stories that become our memories and vice versa, memories that become our story – our narrative identity – and/or mental movies that shape our lives.

> Our memories are prejudiced, in the full sense of the term, by our past history and beliefs. Perfectly faithful memory is a myth, applicable only to trivial objects. The notion that the brain ever holds anything like an isolated "memory of the object" seems untenable. The brain holds a memory of what went on during an interaction, and the interaction importantly includes our own past, and often the past of our biological species and of our culture. (A. Damasio, 2010)

Our memory is fragile and influenced already by the unconscious past history of our genes (epigenetics); thus the emerging media platforms and manipulated information on the Internet "has altered the possibilities of memory recall and input across the globe: moments in time can be recorded, stored, then 'brought back to life, restaged, or replayed'" (Winter 2012, p. 4 cited by U. Linke 2015), making difficult to recognize what is true, and in occasions where the original story comes from. This demands skills for self-inquiry to develop critical thinking in order to question our present situations and past heritage, moreover to decide who we want to be as individuals and communities, as well as what is worth to preserve. It's important to give learners the skills to face challenges and become the directors-creators of their own story, hence be empowered to speak up to transform their lives (Zipes 2004). Social emotional learning takes into account relationships and these aspects; it's a holistic approach similar to the indigenous social narratives, which integrate body, mind, heart and spirit (Dunn 2019). Visual storytelling offers a medium to see, to explore our identity by questioning and reflecting about the knowledge and informative sources that shape our minds spirits, and relationships with each other as with nature.

> Animation is a representational strategy that is particularly suited to documentaries that explore fragmented pasts of forgotten, perplexing, yet often formative memories. The use of animation can emphasize that history and, importantly, memory, are ephemeral and can be a means to counter official and written histories. (Honess 2013)

We share stories from one generation to another, creating collective memories which can be distorted, or bias, depending on the writer/s perspective, context, and integrity (Coser 1992). We participated on cross-cultural projects working on animation as a means of mindful communication (and self-awareness) to preserve collective memory and identity from the artistic perspective of the creative process of visual storytelling (Chin 2004). In Europe, programs, such as the *Creative Learning and Animation* exchange, developed projects to facilitate the integration and adaptation of foreigners, including sensitive work with war refugees; *The Dressmaker, remnants of a life* (Fig. 1) (Carpe 2013) is a short film based on memory loss, where the author used storytelling to recollect some of her family's memories and grandmother's who suffered Alzheimer, questioning what makes the self studying how sharing stories affect our brain and well being (Reed 2014). The animation department of the Polytechnic University of Valencia, Spain, is producing exhibitions, *Animation to transform the World* (Las Naves 2018), and projects for LGTB to raise awareness of disadvantaged people and undermine communities; in Asia, *Animator in Paradise* (Fig. 2) (2016) has conducted several workshops with children,

Preserving the Collective Memory and Re-creating Identity Through Animation, Fig. 1 Textile art. The Dressmaker, Re-Construction of the Self

educators, and artists who wanted to see their community – Otsuki (Animanoiroha 2016) – reflected on local stories from the country side of Japan; in Africa, *Afro Games* (Chapon 2013) was a pilot developed as a TV series by artists from Burkina Faso who wanted to create original content depicting their childhood memories and African culture; in America, audiovisual projects like Amarath (Fig. 3) in Perú, institutions like Docu Perú, TAFA (ambulant workshop of audiovisual training), and TIFA Andina (2017), are working to create and recollect people's voices and myths from native communities; at the same time they use and teach their native languages. These are learning, multicultural and intergenerational projects, which share a common ground; to tell the stories from the protagonists' unique perspective; to heal, to educate and share them as they become visible.

> Narrative identity reconstructs the autobiographical past and imagines the future in such a way to provide a person's life with some degree of unity, purpose, and meaning. Thus, a person's life story synthesizes episodic memories with envisioned goals, creating a coherent account of identity in time. (McAdams and McLean 2013)

Why Animation

Currently it's not very common to conceive animation as a communication media of biographies. Nevertheless, features, as *Drawn from Memory* (1995, Paul Fierlinger), *Waltz with Bashir* (2008, Ari Folman), *It's Such a Beautiful Day* (2012, Don Hertzfeldt), *Wrinkles* (2012, Ignacio Ferreras), and *Rocks in My Pockets* (2014, Signe Baumane), are clear samples of the treatment of the autobiographic memory and narrative identity through animation documentary techniques.

When we produce (and watch) an animated film, we can appreciate how the creation of characters and scenarios become visual metaphors, making possible to visually feel one character's experiences, this is cinematic empathy (Gal & Hendler 2011). We experience, thanks to empathy, imagination, and complex cognitive processes, new virtual situations, which help us to reflect upon thoughts, feelings, and actions, which will build our best movie and legacy: our story life animated. "Our memory is our coherence, our reason, our action, our feelings. Without it, we're nothing" (Buñuel 1983).

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Fig. 2 Storyboard *Treassures of Otsuki*, Japan 2017

Preserving the Collective Memory and Re-creating Identity Through Animation,
Fig. 3 Preproduction of Amaranth short film. Winaypaq, Peru 2017. (Photo of Miguel Palomino)

P

Aristotle defined the Greek word psyche with anima or soul: the principle of life or principle of animation (De Anima, 1987). In time this definition has become more complex and goes beyond the anima, mind, or consciousness. The Greek philosopher considered all forms of poetry modes of imitation or mimesis; animation is mimesis; it can recreate past, present, or future life events as animated "storied lives." Rosemary Rich stated that "it is suggested that individuals construct continuous, ever changing narratives to produce coherent narratives of self – for which Sarbin coined the term 'storied lives'" (2014).

Animation for its power of abstraction and playfulness results in a very attractive and effective media to explore different perspectives and stereotypes (Batkin 2017) to work the neuroplasticity, facilitator of the physical changes of our brain, in order to keep learning within a contemplative context. We learn by listening, watching, and creating stories, real or fiction; they are individual and collective memories. They're visual testimonies, stories that connect us (Gowin 2011), legacies of artistic, historical, educative and therapeutic values (Crothers 2015), which can be preserved through the animation cinema as re-creations of our own identity, as part of the big collective consciousness.

From the beginning of humanity, we can appreciate in the caverns of Altamira the first testimonies of the Paleolithic men. These drawings are samples of animated representations about "the idea" of what hunting looked like or which kind of animals lived at the time. They are memories, printed on painted walls, impregnated with collective identities (Francis Steen 2014). These cave paintings are visual stories – collective memory – of an experience and perception of the reality from that specific period and individuals. Over time we may have changed formats and canvases, but those testimonies are not different from the ones told by Winsor McCay's in T*he Sinking of the Lusitania* (1918), the first animated documentary *Persepolis*, by Marjane Satrapi (2000) or *Ryan* by Chris Landreth (2004). The use of metaphors and symbols as a visual language provides the possibility of using animation to explain concepts of great abstraction and cognitive difficulty, facilitating the access of information to all types of audiences, including groups with lower education. Animation is an artistic expression of emotional energy in movement, a deep reflection that may bring to consciousness the subconscious as a contemplative practice, depending on how the creative process is conducted. Artists from different fields, like Tom Margett (2019), are finding in animation a playground to express memories and personal views; nevertheless one of the greatest potential of animation is being a multidisciplinary medium that provides a platform to the voices that need to speak out and people who need to be seen. "We are lucky to be in the position to tell our stories and we should never take that for granted" (Cusack 2018 cited by T. Margett 2019).

Methodology

From our perspective as lifelong learning artists/educators, animation cinema is a very intuitive language to learn and teach how we are in constant transformation, re-creating the self as our brain collects and edits our memories. During the creative process of a movie, students acquire basic knowledge of the brain functions and the cognitive processes involved to receive, decode, and store information – along with the film language and emotional literacy – to express ideas and feelings within their story. The integration of neurosciences within filmmaking enters the field of Neuroeducation, coined by F. Mora (2013).

It's the brain, together with the mind, the true factory of illusions, our "home cinema," the machinery that processes the thoughts created by the experiences and memories that constitute the personal story and narrative identity (Miller 2010, 2014). The narration that we create every day, shapes and defines our "being" (Daniel Dennet 1992). Nevertheless the brain is plastic, changes and evolves with each learning experience (Davidson 2012); hence understanding our mind is to comprehend our self/others and history.

One of the great similarities between artists, poets, and writers is the ability to link different elements that have no relationship through metaphors. This is one of the primitive forms of the brain that has to extrapolate the common factor

of different concepts and relate them to create new patterns (Ramachandran 2012); this brings us to consider animation a primitive and intuitive means of abstract communication and self-reflection. By understanding how we create stories and movies, students/artists have a media to develop critical thinking, creative learning, and self awareness, becoming the observer and creator of their own story (Hall and Du Gay 1996). Animation offers an opportunity to explore their history and culture to reevaluate values and traditions as they connect with each other. "Learning through aesthetics-in which cinema is included – stimulates a reflective attitude in the learner" (González Blasco and Moreto 2012).

On the projects previously mentioned, inquiry-based learning (IBL), which is socio-constructivist (based mainly on Vygotskian ideas), was implemented as a structure for the work flow adapted to the length and context of each project, from 2 weeks to 6 months of working with children, educators, animators, anthropologists, filmmakers, musicians, and drama teachers as guides. The focus remained on the process despite of the craft level that the final movies would reach. The reflecting phase on the process includes the steps of planning, retrieving, processing, creating, sharing, and evaluating, which are related to areas of affective and cognitive domains of metacognition (Alberta Learning 2004). To reinforce contemplation, drama and music exercises took place as mindful practices during the whole project. The phases of IBL, planning, retrieving, and processing, correlate to preproduction in cinematography; students work in groups – also individually – planning the work, researching ideas based on fieldwork to find the projects' themes and develop a brief synapsis with a storyboard. The creative phase corresponds to production, once the theme is chosen and discussed; different tasks are split among the group to start the animation, which finishes with postproduction. After the movie is rendered, it's shared and evaluated by the whole group. The main technique used was stop motion and mix of media to use our senses and work different materials.

Because animators embody the sensations and thoughts from their characters, the experiential process brings self-awareness opening the mind-heart.

> We remember in different ways at different times: the same memories can be recalled voluntarily, and resurface involuntarily. Moments of the past can be invoked by words, smells, tastes, and sounds: we represent these moments to ourselves in visual images, in stories, in conversations. (King 2000, p. 9)

In the construction of stories, the characters and spaces occur within a structure: a beginning, middle, and end. The animated narrative shows how our brain is prone to predict and seek for stability and continuum, learning to deal with stress and decision-making. Memories are the continuation of our narrative identity and history; animation cinema can be an innovative carrier of the emerging memories and past ones, by adding new insights that may help to avoid future tragedies.

> Tragedy is essentially an imitation not of persons but of action and life, of happiness and misery. All human happiness or misery takes the form of action; the end for which we live is a certain kind of activity, not a quality. Character gives us qualities, but it is in our actions – what we do – that we are happy or the reverse – a tragedy is impossible without action, but there may be one without Character. (Aristotle, 347–342 B.C.)

Conclusion and Discussion

Our self-created narrative identity is in constant evolution as we change, so our collective memory may suffer alterations due to bias, context, or time affects. The creative process of a film allows gaining deep insight to question our past history and present life in order to envision a better future as we become more present and balanced towards equanimity (Smalley and Winston 2010).

The results below are the common factors observed from the experiences working with teachers, artists, and students of different ages, ethnic groups, professions, nationalities, and sociocultural background during the international projects conducted in the last 10 years.

- Increase of self-awareness among the study group and its individuals and growth of connectedness
- Improvement in verbal and nonverbal communication

- Greater resilience and tolerance against other perspectives
- Identification of emotions and better understanding of feelings
- Increase feeling of democracy and cooperation
- Improvement in listening, empathy, and compassion (development of soft values)
- Acquisition of basic level of visual and cinematographic language
- Feeling of comfort or relief by sharing stories
- Rise of self-esteem and security when speaking in front of an audience
- Bigger appreciation of our heritage and personal background
- Arousal of curiosity and learning desire

Animation provides a rich variety of techniques to express and research deeper the psychology of the self and the reconstruction of experiences and memories as valid testimonies for cultural, educational, and health purposes, in the same way they entertain an audience. Visual storytelling has a strong potential to become a contemplative practice to promote cultural heritage (UN 2019), introspection, and well-being.

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Principle Structure to Create a 2D Game Level Editor

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Synonyms

2D game; Game editor; Game level design

Definition

Most modern people are very attached to gadgets and devices in daily life. There are some people that spend most of their time playing video games. Sometimes, one may think to learn to create a video game. Before jumping into the game development area, a beginner needs to know basic knowledge and the basic principle of creating games. For the first-timer, it is better to learn to develop a 2D game for the first attempt since it is the simplest type of game to develop. The entry is a reference work to explore the basic principle of creating a 2D game level editor.

Introduction

Nowadays, many people are concerned about producing a game level editor without required programming. According to Chover et al. (2020), a game engine is designed in order to simplify the development of 2D video games. Al-Najdawi (2007) also stated that a game engine simplifies game development. Unlike game engines, the level editor is only being used as a tool for designing game level but still have the same purpose of simplifying the development of games. In addition, Vaca-Cárdenas et al. (2015) has agreed for the game level editor to enable user associate command to a game object only by dragging command block. Since the games have become an addiction, some people, especially gamers, enthusiasts, are to develop games for satisfaction even though having no knowledge of game development. Researchers recently focused on developing game level editors that are user-friendly for beginners (Aixinjueluo 2021).

Among existing 2D games developed, features like scrolling and spawning enemies are applied. One of the scrolling techniques used frequently is parallax scrolling. In parallax scrolling, farther planes move at a slower rate past the camera than the nearer plane to create an illusion of depth in a 2D scene (Balkan et al. 2003). Adding scrolling in game development has consequences, especially toward the enemies. At some point, enemies run out from the stage, and respawning needs to be set up (Silva and Sedlak 2008).

Among gamers, the term respawn refers to returning to life (Milburn 2018). In the current game, the developer wants the enemies to wait and be invincible until they spawn.

The foreground layer is the closest layer to the observer that use to attract the player's attention (Totten 2019). Many games do not use a technique like adding layers to the foreground layers because it reduces the clearness of the game, especially during parallax scrolling effects because gameplay elements need to be clearly visible (Broms 2021; Romero and Sewell 2019). Diving into coding is needed to ensure the object renderer is visible by the camera. This issue needs to be avoided while developing a game using a level editor without required programming. This is because Cowan and Kapralos (2011) stated that a level editor allows faster iteration times, designing levels visually and require low technical skill for designers.

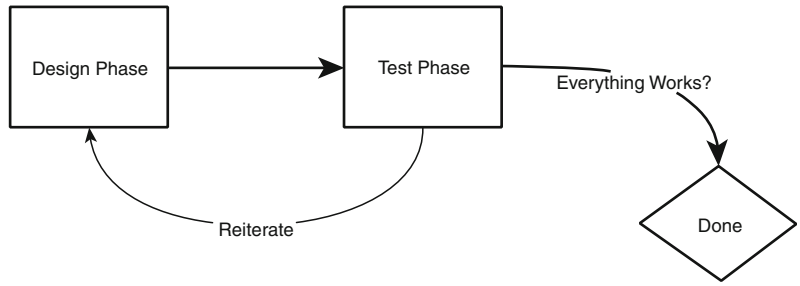
Game Level Editor

A game level editor refers to the program allowing the user to design computer game's environments and may be part of internal software development that can be used only by game designers or may be made as an open-source. Ng et al. (2018) indicated that level editors allow users to customize game levels and their content within a given video game. The roles of the level editor include elements of gameplay, environment, and sophistication of the graphics. Figure 1 shows a simple process of level design using a game level editor that allows the movement between the design and test phase easily. According to Smith et al. (2008), the reason for using the level editor is to make level designing much less technical and allow quick iterations.

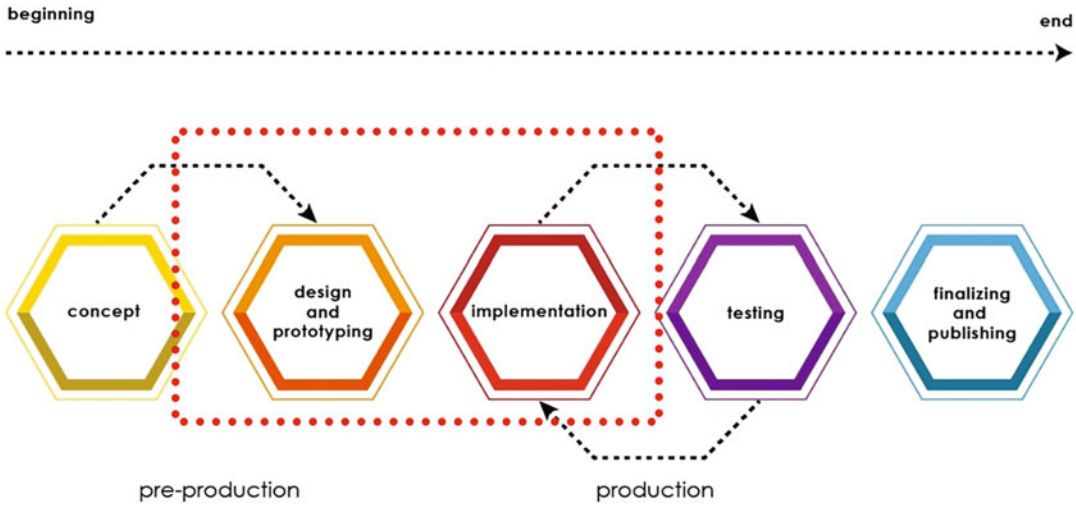
To develop a level editor for a 2D platformer, one must know the things that need to be included in the game level. Felgo (2021) previously suggested a model for platformer level needs to include several different components that can be categorized based on the purpose in the level, such as platforms, obstacles, collectable items, movement aids and triggers. Components of level editor depend on the needs of the game. So, a level editor needs to provide all required components to ensure the user can design the level for the related game.

The interesting part is the innovative systems and methods in a game level editor may give the opportunity for anyone with a young age or no programming experience and knowledge to use it. There are many ways to determine the features in a game level editor depending on its purpose. The most important feature for any game level editor is visualizing the level that means to allow its user to see the world that is being created while simultaneously enabling them to make modifications to it. According to this statement, this is because the user of the game level editor or level designer cannot create a good-looking world if the world's settings are in the editor and the game needs to be run separately by a different application.

The second thing that needs to be considered for the features in the game level editor is to integrate the level editor with the game. A tutorial made by Zhang (2016) had mentioned some important features that need to be tested while integrating level editor with the game. Those features include switching between editing mode and game mode, building level



Principle Structure to Create a 2D Game Level Editor, Fig. 1 Process of level design using the game level editor



Principle Structure to Create a 2D Game Level Editor, Fig. 2 General workflow process of game design

with obstacles, testing the levels, saving, and loading the level. The features must be fulfilled in a level editor to be fully integrated with the game that the user can edit. In addition, the features of the level editor must enable the user to customize the game level within the provided game (Ng et al. 2018). As discussed in the suggested model of platformer level by Felgo (2021), generally, the game needs to include platforms, obstacles, collectable items, movement aids and triggers. But for a 2D running game, it is just enough if the player can avoid enemies or obstacles and gain a score based on the running distance, as mentioned in Ferro and Sapio (2017). So, according to this statement, the features of the game level editor for a 2D running game must enable the user to make a change on player and obstacles or enemies.

A level editor for a platformer such as it works for redesigning a game level for a 2D platformer. Users can undo and redo the editing. Components involved in the game are the avatar, platforms, enemies, collectable items, and obstacles. The background of this game does not require scrolling. Players need to traverse the game to approach farther enemies. The enemies only move in a limited area and are invincible as long as the player does not jump on. This game level editor also provides setting to adjust speed, jump force, and else.

2D Game Design and Gameplay

Game design refers to the design and creativity used to develop games either for the purpose of entertainment or education. Game design usually comes up with game concepts. Game concepts are like an instruction book that becomes a guide for designers and developers to understand the vision of the game that wants to be developed by the team. The game development starts with game concepts that outline the features in-game, goals, and the entire gameplay.

Based on Fig. 2, Ferro and Sapio (2017) illustrate the general workflow process of game design. The preproduction process of game design started with the game concept and was followed by design and prototyping. The game production process involves implementations and testing. The game can be finalized and published after completing all the processes. Figure 3 has indicated the red box, which was in the process the level design might commonly involve. Based on Aaltonen (2018), the level design is one of the subgenres of game design because the design of the game level represents the player's experience in a game that involves interactions. The level design usually aims to satisfy and provide an entertaining experience to customers or users.

The game design is also concerned with game mechanics. Game mechanics refers to the

Principle Structure to Create a 2D Game Level Editor, Fig. 3 2D image usually used for changing background

procedures and rules that need to be followed by the player and the game in response to the player's actions. Apart from that, Winn (2009) and Sae-Lao et al. (2019) agree that game mechanics are formal rules that define operations in the game world, including players' actions, goals, and challenges.

Some game design requires a storyline or plot. Game design is the main theme in the game, including the storyline, plot, and back-stories of characters, but in smaller games and others that do not require significant character or plot like in some racing games, game design refers to the game mechanics.

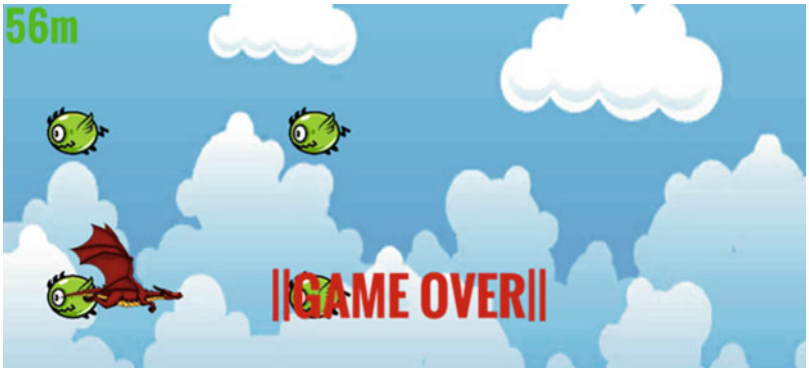
In the gameplay of an endless 2D platform game, two elements that play roles in the game are traps and coins (Fabricatore 2007). In the game, the player needs to move forward continuously to collect coins for scoring while avoiding obstacles that can lead to the game being over. According to Zhang (2016), the player starts running from the left to right side of the screen while avoiding enemies or obstacles by jumping and the highest score is recorded based on the running distance. A player only has one life, which means hitting one time on obstacles or enemies trigger the game to end, high score and current score directly recorded, same goes to the player falling into traps like gaps on the ground. Each gameplay has its own quality. A gameplay has become the key element to judge digital games's quality. The quality of gameplay can be determined by the balance between the level of challenge and the abilities of the player.

2D Game Level Editor Structure

The following sections are to elaborate on the steps involved in order to produce the user editing parts for the level specifications of the 2D game. This includes the elaboration of each different task and feature implemented in the level editor.

Changing Player and Background Sprite

The options to choose different sprites for the player's character to be used in the simple 2D game made we called a changing player. The player is the playable character provided in this game level editor to be played within the 2D running game. The player asset is using 2D sprite since the running game is developed in 2D. All the assets are converted in the form of Unity prefabs so that the scale and rotation of image sprites used can be preserved any time the user selects the asset to be used in the game. In the editing screen, a dropdown is used to display different options for the user to choose the desired character to play with. Only one character can be chosen at a time. Those go the same for the editing options of the background sprite. The selected option is shown in the preview screen provided before the user can proceed to the game scene. They are scrolling background scrolls infinitely during the game. The background sprite is set to that material. Then the material is added to a plane that acts as the mesh for the background. Figure 3 shows the examples of 2D backgrounds commonly used.



Principle Structure to Create a 2D Game Level Editor, Fig. 4 Game over in 2D game

Change Enemy's Pattern, Speed, and Spawn Delay

As for the enemy, this application provides options for the user to change and manipulate the spawn patterns, speed, and delay time. These different options play an important role in determining the difficulties of the game. The enemy pattern editing options allow user to choose two different types of patterns out of four by clicking on the corresponding checkbox that indicates each pattern. The difference between patterns is the formation and position of enemies while spawning to the game. For the speed, it is set for the user to choose from the range of one to ten. Meanwhile, the spawn delay of enemies can be chosen from range one to five.

As for scoring, the score is calculated based on the distance travelled by the player as long as not colliding with the enemies. The distance starts from zero and is set as incrementing by the float value of 0.2. Then, the distance is displayed as an integer in the text as a score during the game.

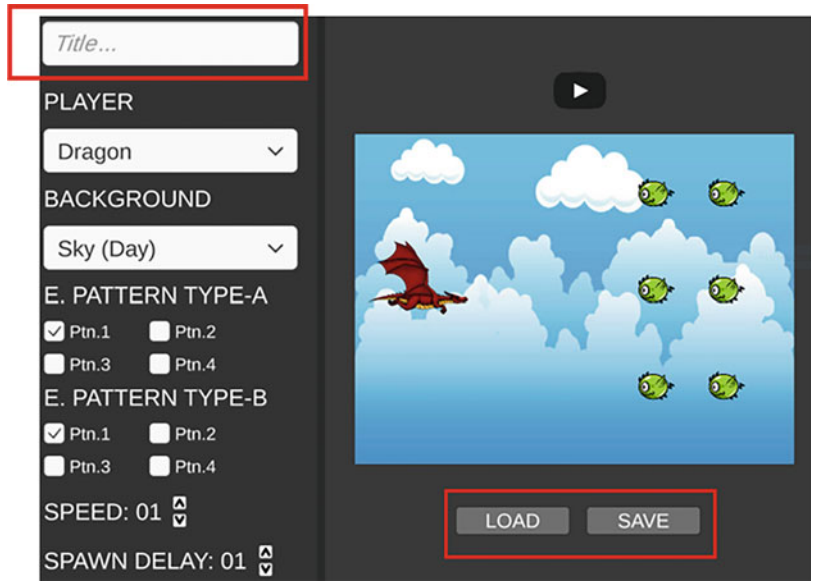
Enemies' behaviors that can be changed in this project include delay time to be spawned, movement speed, and the formation pattern for groups of enemies while spawning to the game. The enemy in the 2D game moves from out of the screen at the right side toward the player. The enemy can be considered as an obstacle for players to move forward.

The game is over, as, in Fig. 4, the condition is triggered after the player collides with an enemy, as explained early for the player's mechanics for this 2D running game. At the start of the game, the initial time is set as one to ensure the screen does not freeze, and the game over text is set as inactive. Meanwhile, if the player collides with the enemy, the game ends. Time is set as zero to freeze or pause the game screen, and the game over text is then set to active.

Import and Export Files

The editor provides options to import or export files that consist of the properties chosen by the player. There is an input field for the title of the game on the editing screen. The exported file is renamed as the title input by the user. The file is exported in the form of .txt format. Users then can import back the data saved in that file to the project.

While exporting a file, the saved file is named by the title and in .txt file format. To mention, the exporting and importing file in this project only supports the .txt file format. Users can click on the "save" button to save all related data that had been chosen in the editing scene and export it as a .txt file. The data saved are converted to either integer, float, or string in the file. To import the data from the edited 2D running game, the user can click on the "load" button to load the file and import all the data from it. Figure 5 shows the "load" and "save" buttons that are located at the bottom of the preview screen for the user to choose either to import or export data on a .txt file. Before going further to exporting or importing the file, there is an input field that requires the user to type a title. The input field for the title can be seen in Fig. 5.



Principle Structure to Create a 2D Game Level Editor, Fig. 5 2D Game Editor with the basic structure

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Prize Crates

▶ Loot Boxes: Gambling-Like Mechanics in Video Games

Problem-Solving

▶ Protection Korona: A Game Design on Covid-19

Procedural Audio in Video Games

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Synonyms

Algorithmic composition; Automatic sound synthesis

Definitions

Procedural audio is a way of making sound and music for video games through the use of generative models which can algorithmically produce material such as sound effects and in-game music.

Introduction

The term procedural audio refers to the use of sound or music in video games that is not pre-sequenced or pre-recorded. Sound designers implement the audio assets as algorithms that generate sound during the game and which, unlike pre-recorded sounds and music, can be incrementally influenced by game data and events. For example, different layers of a musical piece might be combined in different ways depending on the game state or, at a lower level, the sound of a door opening might depend on the angular force applied to it.

Video games often offer a nonlinear experience dictated by the player's actions, and usually, these actions influence the soundtrack and sound effects (Collins (2008a)). Therefore the sound of most games is influenced by input from the player, even if only by which area of the game world they are in or when they fire a weapon (Collins (2009)). Changing the music according to the game level and triggering sounds when the player fires a weapon are not procedural audio though; these examples are missing the critical features of procedural audio systems which is the use of a generative model.

We use the term generative to refer to models utilizing algorithms to produce an output that is not explicitly defined. A simple example is writing several fragments of a musical score and then choosing the sequence in which the fragments are played back at random. Given enough fragments, this "musical dice game" might generate a different piece of music each time.

Farnell (2007) identified further properties that are commonly seen in procedural audio systems. The more relevant properties in the context of video games are:

- **Interactive**: Rowe defined "Interactive Music Systems" broadly as musical systems that change their behavior in response to user input (Rowe (1992)). Procedural audio expands the interaction to include other game objects and events that are not necessarily triggered by the player. The concept of interactivity is not limited to the use of input to trigger sounds but also to change the properties of the sound such as volume and pitch.
- **Nonlinear**: Nonlinear audio generators can move between a number of states in different orders, at different rates, and in different directions (Farnell (2007)). Most musical instruments are examples of nonlinear audio generators, since multiple notes can be performed at the same time in any order. This flexibility helps to create models with complex behaviors able to

adapt to the range of different dynamic scenarios typically present in video games.

- **Adaptive**: Adaptive audio changes according to a changing game or player state (Farnell (2007); Collins (2008a)). For example, if a player is running out of health points, the music might become more discordant to increase tension. This is different from the interactive concept, as the sounds are not so directly influenced by player actions. Despite this distinction, Collins groups interactive and adaptive sound under the term "dynamic audio" (Collins (2008a)).

To summarize, a procedural audio model is generative and uses algorithms to create its output. When programmed in a nonlinear fashion, it can adjust its sound to respond more or less directly (interactively or adaptively) to player input, game events, and game state.

Advantages of Procedural Audio for Game Development

Using models to generate and control sound leads to several advantages.

- **Variation**: In procedural audio, a single model can generate a vast range of different sounds or music through the modification of its parameters. It is not necessary for the composer or sound designer to specify every possible variation. There is an analogy between the evolution of the graphics used in video games and the difference between traditional and procedural audio. Graphics have evolved from simple, sprite-based animation through to 3D models with textures and lighting. 2D sprites define every possible rendering of a game character beforehand, but 3D models are rendered and lit in real-time depending on the position and orientation of the camera and the character, leading to a massive space of possible outputs from the basic models.
- **Efficiency**: Since a single model can generate a vast range of outputs, it is not necessary to use RAM resources to store a large set of pre-rendered sounds. If the model uses pure synthesis, it can take up kilobytes of RAM instead of megabytes. However, the procedural model might require greater CPU resources to execute than a pre-rendered sound player.
- **Coherence**. Using game data to influence the generation of sound and music allows for a deeper and more realistic response to game events. Force vectors can be used to control an impact sound, not only by using a volume control but, for example, adding harmonics or layers to it as the intensity of the hit grows. The interaction between different game objects can be handled automatically, using procedural audio models that receive information about the shape, materials, or movement of the objects impacting them. Duration or style of sounds and music is no longer predetermined but adapts to the nonlinearity of game events, leading to better synchronization and coherence.
- **Modularity**. Procedural audio models can be designed to exchange control data or sound in a modular fashion. In this way, they can be reused or combined differently for different contexts. For example, a procedural animal noise generator can make sounds for several different animals.

Challenges Preventing Broader Adoption of Procedural Audio

Despite the advantages listed above, the games industry rarely adopts procedural audio (Böttcher (2013); Hamilton (2015)). Some of the major factors preventing more extensive use of these models are listed below.

Lack of Tools, Skills, and Time

Building procedural audio models is a complex task that requires knowledge of a wide range of disciplines including programming, synthesis, physical modeling, acoustics, mathematics, and probability theory.

Developing the prototypical model requires an understanding of the desired sonic behavior and tools to translate this behavior into sound. Flow-

based languages for audio like *Pure Data* (Puckette et al. (1996)) or *Max MSP* (Puckette and Zicarelli (1990)) are appropriate for the task (Farnell (2007); Hamilton (2015)) but the development process involves programming and is very different from the traditional sound design workflow.

Even if the sound designer is prepared to use tools such as Pure Data, the target game engine might not integrate well with the tools. Notable developments in this area include the heavy engine by Enzien audio and libPD (Brinkmann et al. (2011)), which allow Pure Data patches to integrate more easily with game engines.

Sound Quality

There are several aspects to sound quality that we will consider here: the realism or perceived quality of sound effects, the musicality of generated soundtracks, and the perceived quality of playback systems for generated soundtracks.

Procedural sound effect synthesis is commonly seen in the games industry as taking more time to develop sounds of a lower-quality than pre-rendered assets (Böttcher (2013); Somberg (2016)). This preconception might be related to the skill requirements and the lack of tools discussed in the previous section rather than to procedural audio itself – a recent perceptual study evaluating synthesized sound effects suggests in fact that sound synthesis can be as convincing as recorded audio samples if the appropriate methodology is adopted (Moffat and Reiss (2018)).

Attaining high musicality in generated scores is a significant challenge in the research field of algorithmic music, especially concerning long-term structure. Current systems cannot compete with the musicality of handcrafted, fixed compositions, despite recent advances in specific areas (Hadjeres et al. (2016)). The evaluation of generative music systems is a complex topic (Collins (2008b)), but Peter Langston, audio programmer for the video game *Ballblazer* (Activision, 1984), gave a simple rule. The game featured one of the first generative music systems heard in a video game. For Langston, procedural music has to pass a "is it interesting music?" test, to be considered successful (Langston (1986)).

Once the system has generated a piece of music in the form of a note sequence or score, the score must somehow be rendered on the fly into audio. This rendering can be done with a MIDI sound bank or with a more elaborate synthesis engine, both of which require more resources than simple audio playback. To put this in context, a precomposed, pre-rendered musical score can be played by a real symphony orchestra, and playback of the recording would only involve a single audio track.

CPU Resources

The adoption of procedural audio leads to increased, but variable, use of CPU resources. Computational cost, in particular, is one of the main arguments contending toward the adoption of these models. However, in a series of interviews run by Böttcher (2013), different academics, audio directors, and programmers confirmed that elements like oscillators or filters could fit the memory constraints of current game audio development (around 5–10% of the total CPU budget). The problem, they outline, is more in the lack of tools and in the change of workflow that adopting procedural audio comports. An example of how issues of efficiency and accessibility were faced is found in the proprietary procedural audio tool developed for Grand Theft Auto V (Rockstar Games, 2013), which we will discuss in the following section.

Applications of Procedural Audio in Video Games

This section describes some state of the art and historically relevant examples of procedural audio systems for music and sound design found in video games.

Music

Ballblazer: The Riffology System

As already mentioned, the menu theme of the game *Ballblazer* (Activision, 1984) is one of the earliest examples of the use of generative music in video games. The system, called *Riffology* and designed by Peter Langston at Lucas Arts, dynamically combines different music segments (riffs),

using a system of weighted random choices. These control elements such as the choice of the riff to play or how to play it: how fast, loud, or if skipping any section inside a musical part. Created to model a "lazy guitarist," the system makes choices both randomly and also by looking at elements like the note distance between different riffs (Langston (1986)). Langston describes the music generated by the system as passing the "is it music?" test but failing the "is it interesting music?" one, due to boring rhythmic and melodic structures that makes it difficult to listen closely for more than 10 min.

Spore

Electronic Arts' *Spore* (2008) is a video game about evolution. The player is asked to direct the evolutionary path of a species, from bacteria in the primordial soup to an interplanetary civilization. The game features an editor in which the user can tailor their creatures for survival. Later in the game, elements like vehicles and spaceships can also be designed. The editor is a key element of the game and one where users could spend much time. To make long sessions enjoyable and to enhance player retention, the developers implemented a generative system for the editor's music (Jolly and McLeran (2008)). The procedural model was developed in Pure Data by audio programmers Kent Jolly and Aaron McLeran, in collaboration with composer Brian Eno. The system consists of two parts – a percussion pattern generator based on different random seeds and a melodic section that works by combining short samples of music. The system alternates intense and calm moments, avoiding repetitive melodies to maintain musical interest over longer play sessions. Moreover, the music changes dynamically according to the player's choices in creature design. If they create a predator, primitive tribal drum patterns will be triggered. Building futuristic vehicles like spaceships later in the game will lead to more synthesized patterns.

Rise of the Tomb Raider: The Dynamic Percussion System

The *Dynamic Percussion System* used in *Rise of the Tomb Raider* (Square Enix, 2015) generates percussion patterns in real-time. It aims to address problems of quality, interest, and accessibility typical of procedural music. MIDI percussion patterns were provided by the composer to be analyzed by the system. The software is then able to generate variations of these patterns of different intensity in real-time. These variations are associated with game states so that during the game the system can dynamically move between them following the action in the game (Lamperski and Tahouri (2016)).

Sound Design

No Man's Sky: The Vocalien System

No Man's Sky (Hello Games, 2015) is an exploratory game where the player moves in a procedurally generated universe. A synthesis system was used to give voice to the fauna that populates the different planets, as it was impossible to know the beasts' traits beforehand during game development and to create appropriate assets for them (Weir (2017)). The system, called *Vocalien*, consists of different oscillators and filters and uses the physical traits of the animals as well as their states (like hunger or aggressive/calm behavior) to generate their voices. It is an example of how procedural systems can be used to defer decisions until runtime and to connect behavior and state to sounds.

Procedural Audio in Grand Theft Auto V

Audio programmers at Rockstar designed a dedicated procedural audio tool for the company's proprietary engine and used it in the development of Grand Theft Auto V (MacGregor (2014)). The system is characterized by a node-based user interface, with an emphasis on real-time visualization of audio and control data to make the system more accessible to sound designers. The developers used the engine for sounds like door slams, metallic impacts, and air conditioners and vents. The system was especially useful for the generation of noisy sounds which can suffer from unwanted artifacts after being encoded to compressed file formats.

Conclusion

Procedural audio is a method of producing sound effects and music for video games which makes use of generative models instead of fixed audio

assets. Procedural audio always makes use of algorithmic processes to generate sound, but it can also be interactive, nonlinear, and adaptive. Procedural audio has several advantages over the fixed asset approach: the audio is more varied, it can be more efficient, it can provide a more coherent experience, and it provides modular, reusable audio assets. Procedural audio faces several challenges to its broader adoption – it demands a different and more extensive skillset than fixed asset production, it can be difficult to match the sound quality of fixed assets, and it has a different computational resource profile. Game developers have used procedural audio to generate music and sound effects in games for many years, including high-profile titles. Such as Tomb Raider and Grand Theft Auto.

Cross-References

- ▶ Dynamic Music Generation: Audio Analysis-Synthesis Methods
- ▶ Sonic Interactions in Virtual Environments
- ▶ The New Age of Procedural Texturing

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P

Procedural Content Generation

- ▶ Planetary Generation in Games

Procedural Music

- ▶ Adaptive Music

Producers

- ▶ Game Prosumption

Professional Call of Duty Player Matthew "Nadeshot" Haag: An e-Sports Case Study

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Synonyms

Clothing brand; Competitive video games; Entertainment; Esports; Lifestyle brand

Definition

Call of Duty	A first person shooter that is published by Activision
e-Sports	A multiplayer competition that is played using video games
Fortnite	A free online battle royale game developed by Epic Games
League of Legends	A multiplayer online battle arena game developed and published by Riot Games
Valorant	A free to play hero shooter developed and released by Riot Games

Introduction

This entry examines the professional career of the former "Call of Duty" professional player Matthew "Nadeshot" Haag. This includes his career as a professional Call of Duty player, his career after retirement from the Call of Duty competitive scene, and the foundation of his e-sports organization "100 Thieves." This entry talks about his achievements and the influence that 100 Thieves has created in the world of e-sports.

Professional Career

Matthew Haag played most of his professional career for OpTic Gaming, one of the biggest organizations in "Call of Duty" with one of the largest fan bases in the entire "Call of Duty" e-sports scene. In 2011, Haag and his team won Call of Duty XP. This was "the first ever Call of Duty fan experience" (Activision n.d.) held by Activision with a prize pool of 1 million dollars. In 2013, his team earned third place in the Call of Duty Championship. The championship is held once a year, and it could be compared to big sports championships like the Super Bowl or the World Series. In 2014, Haag and his team won the MLG X Games Invitational. This tournament "was the first event to feature Call of Duty highlights on national television and the first e-sports event to award X Games Medals" (MLG X Games n.d.). Following the release of Call of Duty Advanced Warfare, Haag and his team went on to win 17 first place finishes out of 29 tournaments. The track record was impressive, until in an unexpected turn of events, Haag and his team were placed seventh at the Call of Duty Championships. This led to Haag announcing his retirement on April 4, 2015, as he believed that he was no longer capable of playing at a level that would not hold his teammates back.

100 Thieves Creation

After Haag's retirement, he went on to found 100 Thieves in 2017. Haag cofounded 100 Thieves with Cleveland Cavaliers owner Dan Gilbert. Since the creation of 100 Thieves, they have "raised $60 M from investor including Drake, Scooter Braun, Cleveland Cavaliers Owner & Quicken Loans Chairman Dan Gilbert, Artist Capital Management, Ludlow Ventures, Green Bay Ventures, and Sequoia" (About Us n.d.). Haag is the founder and CEO of the organization to "lead the company's creative, brand, and strategic direction" (About Us n.d.). In April 2021, it announced that popular content creators Rachell "Valkyrae" Hofstetter and Jack "CouRage" Dunlop (Waananen 2021) would become co-owners of 100 Thieves.

100 Thieves Influence

100 Thieves is an entertainment, gaming, and apparel organization. They have created multiple

competitive teams for e-sports games such as League of Legends, League of Legends Academy, Fortnite, Call of Duty, and Valorant. 100 Thieves has also created an amateur League of Legends team called 100 Next to "assist younger players new to the competitive scene" (100 Thieves Next n.d.). These teams have "won multiple major championships" (About Us n.d.) during the first 2 years of the organization's life. Along with the teams' competitive teams, they have signed multiple popular content creators, including BrookeAB, Classify, CourageJD, NoahJ456, Valkyrae, and many more (Teams n.d.). 100 Thieves sells apparel, which has sold out on 12 different apparel drops. They also "launched the top gaming podcast on iTunes" (About Us n.d.). Another contribution they have made is opening up the players' training facility in California for use as a vote center for the 2020 United States presidential election.

Conclusion and Discussion

Matthew "Nadeshot" Haag had a very successful professional Call of Duty career.

Winning multiple tournaments with OpTic Gaming includes one of four of the first X Games Gold Medals to be awarded for an e-sport competition at the X Games. After his retirement, Haag has become successful as the co-founder of 100 Thieves. 100 Thieves has undoubtedly become one of the most influential organizations in e-sports and entertainment. Haag exemplifies a successful transition from being a professional gamer to an e-sports entrepreneur.

Cross-References

► Call of Duty Franchise, an Analysis

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Programming

► Virtual Reality Game Engines

Project Management

► User-Centered Design and Evaluation Methodology for Virtual Environments

Project Planning

► User-Centered Design and Evaluation Methodology for Virtual Environments

Project-Based Learning

► Challenge-Based Learning in a Serious Global Game

Proprioception

► Spatial Perception in Virtual Environments

Protection

▶ Protection Korona: A Game Design on Covid-19

Protection Korona: A Game Design on Covid-19

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Synonyms

Board game; Corona; Covid-19; Game design; Pandemic; Problem-solving; Protection

Definition

Covid-19 has become a global health crisis in the year 2020 that has brought the entire world on a standstill. The title "Protection Korona" is the name of a game designed on Covid-19 to help impact and educate people to protect themselves while learning about ways to remain safe and healthy.

Introduction

Covid-19 has brought the world on the edge with its uncontrolled spread. People are unaware of facts and are hence formulating their solutions with half-knowledge about the pandemic, thereby inducing an atmosphere of fear. This entry will talk about how we can use games as a medium to solve this problem of people not knowing about the pandemic. This entry will take "Protection Korona," a game designed on Covid-19, as an example to explain how game design can be a great solution to tackle social problems easily and interactively that would make the people want to engage in willingly. This entry will also touch upon the three main areas that you need to have an understanding of while designing a game to tackle is a serious problem.

A Touch upon the History of Games

Games have been known to have existed for more than 9000 years. These include sports, play as well as board games. Even though tabletop games can be traced back to ancient times, not all of these games were designed by a designer but rather came into being and were then developed and improved according to the folk process and modern times. Today many of these traditional games have been commercialized to fit the interest of the people and are used widely. Thus, games have been a part of the human race for a long time and have been a part of every individual's life at a point in time.

Game Design as a Solution

Wikipedia defines game design as the "art of applying design and aesthetics to create a game for entertainment or for educational, exercise, or experimental purposes." While this is correct in technical terms, game design can also be interpreted as the art of creating experiences that are fun, and that makes you indulge in activities that help to exercise your brain. Games are a great way to engage people and research shows that people are more inclined toward interactive ways of learning rather than theoretical versions that give you only information and no entertainment. Games create curiosity and act as a drug for learning.

Games are a great way to engage the young generation as well as older people and act as an easy and effective way of introducing essential cognitive skills in them. They not only help you with decision-making but also act as a bridge between knowledge and its application. They

make you curious and thereby help you learn things that you wouldn't otherwise. They give you a platform to make mistakes and solve them which gives you a practical approach and thereby helps you to remember these learnings. As playful animals, we love to create, cocreate, construct, and deconstruct our "real" world through gaming (Kriz 2020). This characteristic of humans is what can be used as a way to educate them about the things that they ignore otherwise. Games are a great solution to make people aware of the problems and issues around, in an easy and lighter way making sure that it is not misinterpreted.

Times of Covid-19

As we know, 2020 is facing the pandemic of Covid-19 and has brought the entire world on a standstill. People are dying around every day and news and media are creating fear in the minds of the people so much so that people are finding it easy to believe in misconceptions than to find facts about the pandemic.

During this time of pandemic, there has been an increase in people indulging in games as a past time. There are many games that deal with the topic of pandemics. These games are usually a hybrid mixture of entertainment and educational games. They help people to understand complex situations and how to deal with them while having fun and keeping positive. They invoke a sense of responsibility in people and hence indirectly make them aware of the problem.

One such example (See Fig. 1) of a game on Covid-19 is "Protection Korona" which is a board game designed to tackle the lack of awareness in the people about the pandemic as well as sensitize them toward taking actions and do their part to remain protected and safe. This entry will further highlight how the game has acted to be a good solution and how it affects the players.

Protection Korona

The board game is designed to have four main character roles that the players can play as which are doctor, police, researcher, and public. Having roles in the game helps the players to emotionally connect with their character and also understand their role in real life, thereby making them a little sensitive each time they play or act on their role duties. The goal of the game is that the first person to cross all the four parts of the board and reach back to where they started without getting affected

Image source – Created with Adobe Illustrator

Protection Korona: A Game Design on Covid-19, Fig. 1 A board game's visual design

wins the game. There are protection item cards that the players have to collect in order to remain safe and not get affected by the virus. The game's USP is that it allows you to trade your cards with the other players in order to help them in case they are to be affected. This characteristic feature of the game is to encourage the players to resort to unity and makes them understand the importance of playing and fighting the challenges of the pandemic together as a team.

Players have to face various challenges throughout the game and overcome them by making preinformed decisions. The board contains various tiles that have "health items" for boosting immunity, "virus tiles" that will infect the players, and "protection item tiles" that will give the player's protection equipment to collect and trade in order to remain immune to the game.

The game also has immunity booster scales that will update each time a player lands on an infected tile or a virus tile. This will help the players remain attentive throughout the game. The game also has quarantine and hospitalization zones that will educate the players as to when they need to do either of them. Each role that the player will play will give them a duty and role to play in the game. This will not only make them aware of the problems that these character roles (doctors, police, public, and researchers) face but will also help them to relate with them.

Being a family game with dimensions that are sufficiently big, the players will be sitting far apart from each other and will also be following the same social distancing norms as a part of the game. The game has been designed in such a way that the players will by the end of it know every small and relevant detail that they need to know about the pandemic and also how to help themselves and those around them by maintaining strict distancing.

The game will help the players to know about the importance of unity in these terrible times and will help them to develop respect and sensitivity toward these really hard-working characters of our society who are helping every day toward protecting the world and the people in it.

Conclusion

The testing of the game showed that people started to ask questions about what they had seen on the media and news channels about things that were fake and they appreciated the game for helping them learn the facts. The game that was curated based on the suggestions of the people also showed great changes in the way their mindset was about the different heroes of this pandemic. It's safe to say that the game proved to be a great solution to educate people about the pandemic and make them feel for those fighting out there to save the public every single day and to curb it. This leads us to think that perhaps games are a great and easy way to make people interested in knowing about topics that otherwise seem scary and too much to take.

In this era where people are tired of the information deliverables around them, games are a very innovative and interactive way to make them aware of the problems and also help them spend some quality time with their family while doing so.

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Protocol

► Simulation and Comparison of AODV and DSDV Protocols in MANETs

Proton Beam Therapy Unit

► Virtual Reality Proton Beam Therapy Unit: Case Study on the Development

Prototyping

▶ Analog Prototyping for Digital Game Design
▶ Collaborative Engineering and Virtual Prototyping Within Virtual Reality

PSI

▶ Parasocial Phenomena in Video Games

PSP

▶ Parasocial Phenomena in Video Games

PSR

▶ Parasocial Phenomena in Video Games

Psychological Game Design

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Synonyms

Psychology in Game Design

Definition

Psychological game design is the use of psychological principles in game design to enhance player experience and engagement.

Introduction

Research on psychological aspects of digital games has been rising within the last decade. Game companies also started to hire psychologists to conduct research and implement psychological principles in their game designs. In this article, major psychological theories that are applied to game design are briefly introduced.

Operant Theory

Operant theory (Skinner 1953) mainly suggests that rewards motivate desired behaviors, and the frequency of a behavior depends on the schedule of the rewards. Rewards might be provided after a fixed number of behaviors (i.e., fixed ratio) or after a variable number of behaviors with an average ratio (i.e., variable ratio). Similarly, reward schedules might also be based on time intervals rather than the number of behaviors (interval schedules). In general, ratio schedules result in higher response rates than interval schedules, with variable ratio schedules resulting in the highest response rates.

These different types of schedules of reinforcement are one of the most frequently used elements of psychological game design (Lewis et al. 2012). Players engaging in repetitive and boring game activities merely to obtain a desired in-game reward (called "grinding" or "farming") that is provided on a variable ratio schedule, free to play games that require waiting for a fixed amount of time (a fixed interval schedule) unless the player pays money are some examples of the use of operant theory principles in game design (Uysal and Yildirim 2016). It should be noted that although such applications increase playing time by putting players in a Skinner box, they do not necessarily increase enjoyment. In contrast, these external motivators are more likely to have adverse effects on player's satisfaction and well-being (King and Delfabbro 2009; Przybylski et al. 2009).

Self-Determination Theory and Basic Psychological Needs

According to self-determination theory (Ryan and Deci 2017), people have three basic psychological needs. Autonomy refers to having choices and fully endorsing one's actions, competence refers to feeling effective and capable, and relatedness refers to feeling close and connected to others. Satisfaction of these needs is essential for psychological well-being.

The principles of basic need satisfaction have also been applied to game design. Studies show that games that satisfy autonomy by providing choices and freedom, competence by providing optimal challenge and clear feedback, and relatedness by providing a sense of connectedness to the game's digital world or player community are found to be more enjoyable and highly rated by players (Ryan et al. 2006). Several examples of the applications of basic need satisfaction in various genres of games are provided by Rigby and Ryan (2011).

Technology Acceptance Model

Technology acceptance model (Davis et al. 1989) is an application of the theory of planned behavior (Ajzen 1991) to the field of information systems. According to TAM, salient beliefs such as perceived ease of use and perceived usefulness of a system are the main factors that predict people's intentions to use a technology, which in turn predicts actual use.

Although TAM focuses on utilitarian systems, the model is also expanded to hedonic systems (Van der Heijden 2004). In hedonic systems, perceived ease of use was conceptualized as the primary antecedent of perceived enjoyment. Indeed, perceived usefulness could be less applicable to games as gamers are more focused on fun rather than utilitarian values of a game (Lowry et al. 2012). Nevertheless, the model introduces perceived ease of use, a factor that is closely related to game design elements, as an antecedent of enjoyment. Thus, game features that make the games more accessible to players and increase the games' ease of use are also likely to increase the player's enjoyment (Hsu and Lu 2004).

Social Cognitive Theory

According to social cognitive theory (Bandura 1986), people evaluate the expected outcomes of a behavior based on their observations and past experiences. These expectations, along with some other personal and environmental factors, play a key role in determining whether the person will engage in a behavior.

Focusing on the role of expectations, researchers applied SCT to games and identified some game design elements that fuel player engagement (Lee and Larose 2007). Accordingly, providing agency by allowing players to determine their own actions, presenting a believable and convincing narrative, setting achievable goals that result in a good performance, and allowing players to interact and socialize with other players are the main in-game elements that increase player engagement (De Grove et al. 2016).

Investment Model

Investment model (Rusbult 1983) is a relationship model, which identifies three independent factors that predict commitment to romantic relationships. Accordingly, satisfaction with the relationship, quality of alternatives to the relationship, and people's investment to their relationship are antecedents of relationship commitment. Thus, people might still be willing to continue their low satisfaction relationships, if they do not have alternatives to their relationships or if their investment in their relationships is high.

Similarly, game elements that increase players' investment in the game also increase their commitment to the game, independent of their satisfaction with the game (Uysal 2016). For instance, players of games with persistent virtual worlds

(e.g., MMOs) might have invested a considerable amount of time and effort to their virtual characters, which maintain their commitment to the game independent of their satisfaction levels. Similarly, game companies started to employ microtransactions more and more frequently in their games mainly to increase their revenue; however, these transactions are also increasing players' monetary investment in the game, resulting in greater player commitment.

Conclusion and Discussion

These studies show that the field of psychology provides a rich perspective for game design focused on enhancing player experience. Although exploitation of psychological research, especially external motivators, by game companies to increase profits also brings some ethical concerns (Søraker 2016), better-designed games that focus on intrinsic motivators would contribute positively to the well-being of players. Nevertheless, the field is relatively new and psychology has a lot more to offer (Bostan 2016) for understanding what makes games more enjoyable and fun.

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Psychology in Game Design

▶ Psychological Game Design

Public Health Education via Computer Games

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Synonyms

Edutainment; Purposeful games; Serious games; Transformative games

Definitions

Purposeful games	These are games which have specific objectives besides entertainment, like providing new knowledge to the player on a specific topic or enhancing the usage of existing knowledge, or improving his/her motor skill, benefitting him/her directly, or using the player to serve some other purpose like generating data for machine learning using gameplay, e.g., a game may require a player to match products with customers and the player's answers may be used to train a computer program to perform this task automatically in the future. Though the player matching the products and customers may be paid, she/he may not get any intellectual benefits or improve motor skills.
Serious games	These are purposeful games intended to benefit the player directly by providing new knowledge or enhancing the usage of existing knowledge, or helping the player improve some motor skill, to change his/her thinking or behavior. The intended benefit may or may not be long-lasting, e.g., the benefit provided by a serious game intended to train a player to solve problems based on a topic in an optional academic course may be short-lived if the player is taking the course just to fulfill graduation requirements, but the impact of a game intended to teach safe driving may last lifelong.
Transformative games	These are serious games intended to directly provide a long-lasting benefit to the player by positively transforming his/her thinking or behavior, e.g., a game teaching the player to manage money or emotions or priorities or relationships with peers or storage space better is a transformative game.
Edutainment	It is an educational entertainment. Serious games provide edutainment.

Introduction

Educating the public about health via computer games is very important because not everybody can see qualified medical professionals due to temporal, spatial, or financial constraints. Also, some people find computer games more engaging than counseling, clinical visits, reading literature, or listening to lectures. Scalability and the ability to educate almost ubiquitously make carefully designed computer games very effective for reducing healthcare costs and supplementing traditional medical care. This entry is a short but comprehensive survey of implemented and evaluated computer games and game-like virtual environments intended to make people aware of health problems and their consequences, unhealthy

habits, and misconceptions about health and inspire them to take better care of themselves. The emphasis of the entry is on covering health problems addressed by computer games and not on covering all computer games addressing individual health problems.

Alcohol Consumption

Excessive alcohol consumption is known to have bad effects on brain, heart, liver, pancreas, and immune system and increase the risk for multiple kinds of cancer. Driving under the influence of alcohol jeopardizes drivers as well as passengers and is known to cause thousands of fatalities worldwide each year. Persons consuming alcohol excessively may cause physical/mental harm to others or break laws. CollegeLive (Hughes et al. 2016) is a virtual environment for letting users experience social interactions that are typically experienced by first-year college students. This environment is intended to promote prevention of drunk driving and sexual advances by/toward drunk people and rationally handling peer pressure leading to these behaviors.

Anxiety and Trauma

Above Water (Wehbe et al. 2016) is a game for educating players on generalized anxiety disorders and panic disorders. These disorders involve excessive worry or fear which is often irrational. Besides reducing productivity, they can be debilitating. Physical symptoms may accompany mental symptoms of these disorders. Above Water is a hybrid game because players play using electronic devices and physical cards about (i) life goals, (ii) anxiety, (iii) treatment, and (iv) sharing a strategy helping them or tips or a question. Some treatment cards activate an interactive experience using deep-breathing app or yoga-and-stretching app.

Witnessing natural disasters, violence, accidents, physical or mental abuse, or their effects can be traumatic. Cognitive behavioral therapy (CBT) is a widely used drug-free paradigm for minimizing the impact of such trauma. The game in (Assigana et al. 2014) is for educating children on CBT. Children playing this game help animals in distress by generating alternate thoughts to promote positive feelings and wholesome behavior.

Attention Deficit Hyperactivity Disorder (ADHD)

ADHD is a brain disorder characterized by continued distraction, unnecessary and frequent movement or talk which may be disruptive, and actions exhibiting impatience or lack of forethought. Drawn to Distraction (Goldman et al. 2014) is a game intended to convey to caregivers of children affected by ADHD and non-caregiving people that people with ADHD have a stronger drive to engage in activities offering immediate rewards even when they know that activities offering much higher rewards and requiring patience are available. The game is intended to convey that ADHD symptoms may be mistakenly perceived as intentional negligence. Such a misunderstanding can result in a punishment for a child not doing a homework instead of treatment for ADHD. The playing character in the game is expected to reach library to study for an upcoming examination which is an activity with higher and delayed reward, resisting the temptation to play a game called Space Raiders which represents an activity with low and immediate reward.

Autism Spectrum Disorder

Autism spectrum disorder is a developmental disorder that refers to problems in interaction with other people which vary in type and severity. Autistic people are often very shy which can lead to problems in relationships and professions requiring interaction with coworkers, peers, bosses, or customers. Pinwheel (Kolakowska et al. 2017) is a game playable on tablets which has been used to measure progress of children with autism spectrum disorder. A child has to

flip the tablet correctly to move the colored ball from the base of the pinwheel's stem to the petal with matching color. Sensing by touch screen, accelerometer, and gyroscope provides information in addition to the information recorded by the game. The number of successful and wrong hits and mean reaction time for them are among the six gameplay features used to measure progress in one or more areas of development. Fine motor skills and attention control are among the ten areas of development used in this study. Therapists' evaluations of 31 children in the 10 areas of development along with gameplay statistics were used as training data for supervised inductive machine learning. The goal of machine learning in this study was to learn to predict child development in different areas using gameplay statistics. Child development-related decisions found by the learning program can be used by therapists in their decision-making. This study is an excellent example of the synergy of qualitative decision-making by humans and intensive computation by computers.

Diabetes

Diabetes results from insufficient insulin or inefficient use of insulin. Uncontrolled diabetes leads to excessive glucose in blood which can damage vision, nerves, kidneys, and increase the risk for cardiovascular disease. Food Quiz (Glasemann et al. 2010) is a game which teaches diabetic people to count carbohydrate content in food, since carbohydrate intake affects blood sugar. A player is shown a plate with food and asked to find the number of bread units in the food. One bread unit represents 10–12 g of carbohydrates in Germany depending on the geographical region. Lower levels of this game show individual food items. Higher levels of the game show a combination of food items or dishes. Mario Brothers is an open-source game. Its modification presented in (Chen et al. 2011) is intended to educate diabetic children. Mario – the main character of the modified game, has type I diabetes. Mario has to control his blood sugar during his mission to save the princess locked in a castle. The player has to control Mario's blood sugar by making wise choices about food intake, exercise, and insulin injection. Power Defense (Bassilious et al. 2012) is a game intended to improve the ability to understand and control the numbers related to management of type I diabetes. In brief, food attacks a reactor-based base station which represents the diabetes patient in this game, and the player has to survive the attacks by ensuring that the amount of energy (represented by food) reaching the base station is in acceptable range. The reading of the power-output meter of the base station represents blood sugar.

Hygiene

Hygiene is about maintaining a clean body and environment to minimize the chance of spreading infectious diseases. MicrobeQuest! (Molnar and Kostkova 2015) is a game which allows the player to explore human hand or body or food to learn about microbes, microbe transmission, and food-and-body hygiene.

Maternal Health

Improper nutrition during pregnancy can lead to poor health outcomes for children. Ultrasound examinations during pregnancy help in assessing fetal health and growth. EasyCare (Font et al. 2017) is a game for educating women on nutrition and water consumption during pregnancy and after delivery and ultrasound examinations during pregnancy.

Nutrition

Child obesity is a serious problem since obesity increases risk for many chronic health conditions which lead to death or permanent disability. The comic-book-style interactive storytelling mobile application in (Amresh et al. 2015) educates children on healthy eating to prevent overweightness and obesity. The application is intended to teach children to create a balanced meal and incorporate

physical exercise in their schedules. A child can replay to select different choices to find a winning combination.

Physical Exercise

Physical exercise is very important for maintaining/improving strength, flexibility, and cardiovascular health and preventing or delaying the onset of many serious health conditions. Physical exercise also plays a very important role in improving/maintaining mental health. World of Workout (Bartley et al. 2013) is an application promoting physical fitness through physical exercise. A player can improve the speed, strength, and stamina of his avatar by doing relevant exercises. Activities that don't require a significant change in the player's location (push-ups, jumping jacks, and sit-ups) are recognized using accelerometer in his/her smartphone. Activities needing significant changes in the player's location (walking, running, and sprinting) are recognized by analyzing the information provided by the GPS (global positioning system) in the player's smartphone.

Physical Therapy

Physical therapy is intended to improve quality of life by improving posture, balance, mobility, flexibility, or strength. Candidates for physical therapy include but are not limited to athletes, developmentally challenged children, and stroke survivors. The computational intelligence-based architecture in (Afyouni et al. 2014) includes a route recommender which accepts primitive hand gestures recommended for a disabled patient by a therapist along with movement constraints (speed of movement, maximum range of motion, and number of repetitions of the movement) and generates a customized route in the gaming environment for the patient to move hand accordingly, to undergo physical therapy. iSpine presented in (Hsu et al. 2013) is an educational entertainment system for children suffering from scoliosis. People with scoliosis have an abnormally curved spine. Though most scoliosis patients have a mild form of it, severe scoliosis can cause damage to lungs and heart and increase the risk for chronic back pain. iSpine is designed to teach 9 orthopedist-designed physical exercises and 33 spinal health concepts. iSpine allows children to improve the health of their virtual pets by performing physical exercises. iSpine uses motion-sensing devices.

Sexually Transmitted Infection (STI) and Cervical Cancer

Human papillomaviruses (HPV) infect millions of people worldwide each year. HPV is the most common STI. High-risk HPV can cause different cancers including cervical cancer. The game in (Nirmal et al. 2013) is intended to educate people on HPV and cervical cancer. Up to four players can play this game at a time. A player earns a card by correctly answering if the given statement about HPV or cervical cancer is a fact or myth, but taking an educational test with these questions costs coins. The feedback from 111 participants showed that around 96% gained some or significant knowledge by playing the game. UnderControl (Guana et al. 2014) is a multilevel mobile game which educates players on available contraceptives, safe sex, birth control, and ways to prevent STI.

Conclusion

Though results obtained from computer games and game-like virtual environments developed for public health education are impressive, many of these games are not available in public domain. Also, there are still many major health conditions and their special cases that have not been addressed by computer games.

Cross-References

▶ Games
▶ Serious Games

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Publishing

▶ Itch.io, History of

PUN: Photon Unity Network

▶ Interactive Augmented Reality Pop-Up Book with Natural Gesture Interaction for Handheld

Purposeful Game

▶ Strategies for Design and Development of Serious Games: Indian Perspective

Purposeful Games

► Public Health Education via Computer Games

Puyo

► Puyo Puyo

Puyo Pop

► Puyo Puyo

Puyo Puyo

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Synonyms

Puyo; Puyo Pop

Definition

Puyo Puyo is a series of tile-matching, two-player, and real-time puzzle games published by Compile Inc. and Sega Inc.

Introduction

Puyo Puyo is a series of two-player real-time puzzle games published by Compile Inc. from 1991 and Sega Inc. from 2002. Over ten titles have been published for over ten platforms and have been played and studied for a long time especially in Japan.

Puyo Puyo is a kind of tile-matching puzzle game with dropping tiles such as Tetris, Dr. Mario, or Columns. While such games were mainly designed as one-player game, it is important that Puyo Puyo was designed as a two-player game, and many competitions have been held for expert players, like the cases of fighting games or real-time strategy games.

In this entry, core rules, brief gameplay, and some approaches from researchers are described, as detailed rules and characters of each title; history and anecdotage are omitted.

Core Rules

There are many rules in Puyo Puyo series, and different set of rules are used in each title or each game mode. Here the most common ones are described. As the official page (http://puyo.sega.jp/ is in Japanese, English Wikipedia (http://puyonexus.net/wiki/) may be useful.

Number of Players and Boards

Puyo Puyo is usually played by two players; each player has his own board (field) with about 6×13 tiles (Fig. 1a), as both boards are open to be looked at.

While a single board is shared by two players and they can interfere the other directly in chess, Go, or fighting games, players can interfere the other only indirectly through "chain" in Puyo Puyo.

Operations

In Tetris, the connected four tiles called tetromino are given to the player, the kind of tetromino is randomly selected from seven candidates, and the player rotates/moves horizontally and drops it. In Puyo Puyo, each tile is called puyo, and usually each puyo is colored. In each turn, connected two puyos are given; the player also rotates/moves horizontally and drops it (Fig. 1b). Colors of given puyos are randomly selected from four candidates, but the next four colors (of the next two turns) are announced (Fig. 1c).

In contrast to sequential games such as chess, actions and events of players in Puyo Puyo are

processed in a real-time manner, and almost no synchronization is done. Aside from the intended drop by a player, the given two puyos are drop gradually by time.

State Transition

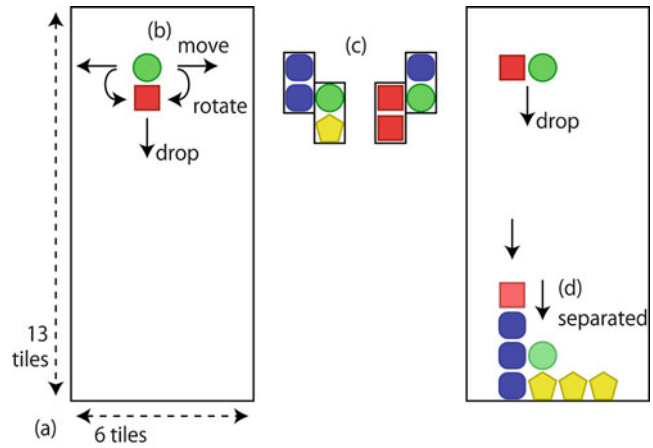
When one of the two given puyos grounds on the bottom edge, or one of the existing puyos, the player's operation is complete. In contrast to the case of Tetris or Dr. Mario, two puyos can separate and drop independently to the surface (Fig. 1d).

If four or more puyos of the same color are connected horizontally or vertically, they are eliminated from the board (Fig. 2a). After some puyos are eliminated, there may be some puyos over them. Such floating puyos fall to the surface (Fig. 2b). After the fall, if four or more puyos of the same color become newly connected, they are also eliminated (Fig. 2c). Such cascade of elimination is called a "2-chain." In the same way, 3-chain, 4-chain, or n-chain may occur.

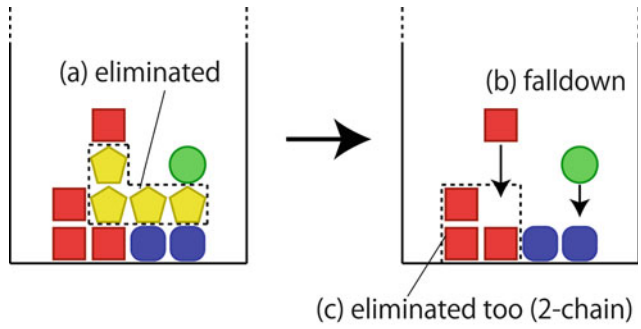
Attack and Win

Each player gains his score mainly by finishing a chain, though there are some other resources such as just dropping puyos or clearing all puyos. By gaining a score, the player can attack the opponent by sending "garbage puyos" (or "nuisance puyos"). The longer the chain or the more puyos eliminated, the more garbage puyos are sent.

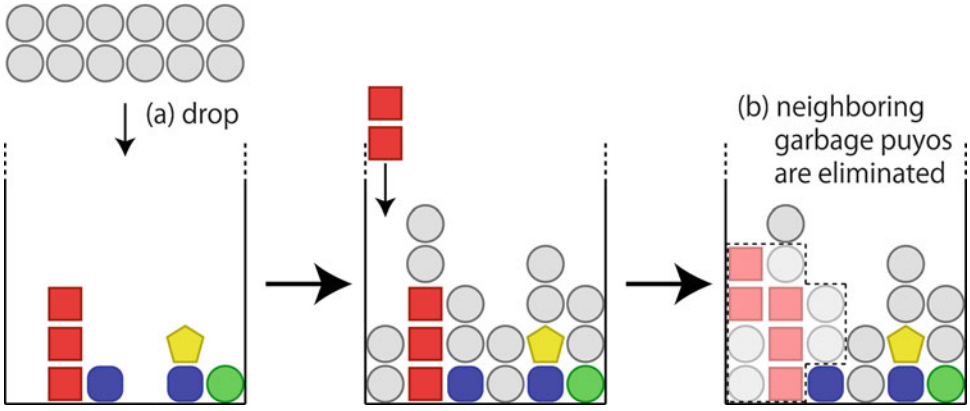
Sent garbage puyos are dropped to the surface after the operation of the attack player (Fig. 3a). Garbage puyos cannot be eliminated by themselves; then usually they disturb the making of chain of the attacked player. Garbage puyos can be eliminated only if neighboring colored puyos are eliminated (Fig. 3b).



Puyo Puyo, Fig. 1 Boards of Puyo Puyo and possible operations



Puyo Puyo, Fig. 2 Elimination and chain



Puyo Puyo, Fig. 3 Garbage puyos

An essential rule "cancelation" of garbage puyos was introduced at Puyo Puyo 2, and now the rule is used as a standard. When both players executed chains and sent garbage puyos, they can cancel and only the difference of the amounts is sent. For example, player A sends 140 garbage puyos by 7-chain, player B sends 60 garbage puyos by 5-chain, then only 80 puyos are dropped on the board of player B. When the third column from the left is filled, the player loses the game.

Game Modes

Several game modes are available in commercial titles of Puyo Puyo, and different skills are required.

1. Story mode, human versus computer. Human player plays against about ten enemies sequentially. Each enemy has its own character, such as skeleton or mage, and own strategy to play.
2. Human versus human. Usually rule set can be modified, and handicaps can be added.
3. Endless mode, human only. Only one board is used, the goal of this mode is not beating the opponent but gaining as much score as possible. The speed of unintended drop becomes faster gradually.
4. Quiz mode. Single board with preset puyos is given, player plays to realize the given goal such as "do 4-chain" or "clear all puyos" in some turns. Usually long time is given to think.

Gameplay and Basic Strategies

Though required skills for each game mode are a bit different, here "human versus human" is assumed and the basic strategies for it are shown. The main way for attacking in Puyo Puyo is to prepare and execute the chain, and the longer chain can attack more strongly. Between intermediate and expert players, it is required to prepare long chain such as 13-chain, as faster as possible, with less weak point to be exploited and with checking and disturbing the opponent preparation.

Preparing Chain

To construct and prepare chain is the necessary skill for Puyo Puyo. Here some basic shapes of chain preparation are introduced.

Figure 4a shows the basic shape called "stair 5-chain." By eliminating the leftmost blue puyos, yellow, red, green, and finally blue puyos are eliminated step by step. The amount of garbage puyos sent by this 5-chain is about 60, then almost enough to win if the opponent cannot cancel. In the Puyo Puyo 1, before the introduction of cancelation rule, the only point to win was to execute 5-chain before the opponent.

Figures 4b–d show other shapes of 5-chain, though the order of eliminated colors is the same. As there are a lot of and varied shapes in chain, each of them has its own advantages and disadvantages, an adequate one should be selected

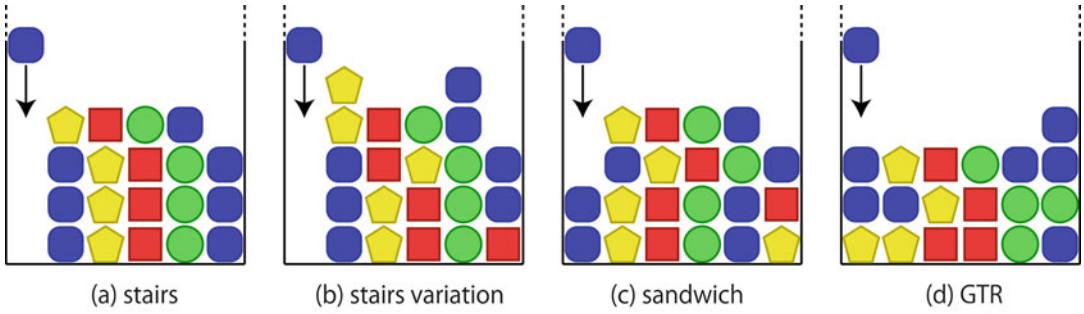
by considering the given puyos and the opponent situation.

Figure 5 shows an advanced but famous shape called "transition." By eliminating the rightmost upper yellow puyos, chain proceeds to left, and at the left edge the direction transits to right; finally 11-chain is executed. This 11-chain includes 5-chain shown in Fig. 4a, but usually this subpart is not constructed at first; the left side of 11-chain (transition part) is preferentially constructed at first. Sometimes, one more transition part is constructed at near the first yellow puyos; totally about 15-chain can be done.

Decreasing Time Loss

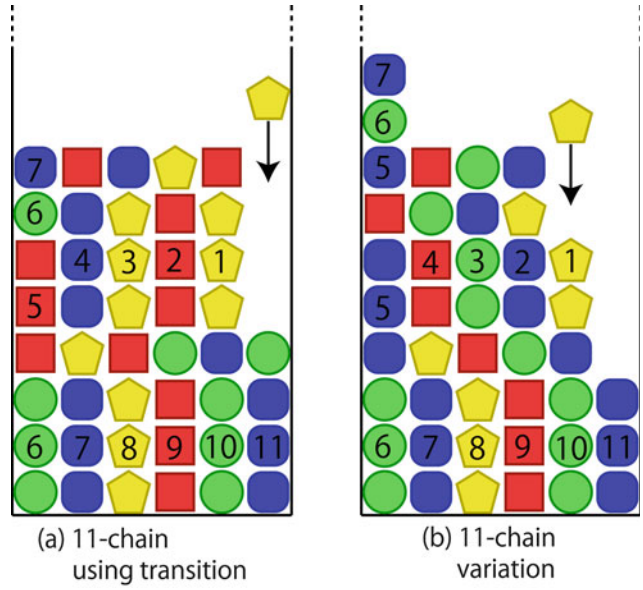
As Puyo Puyo is usually a real-time game, a time loss by operation delay causes the loss of number of dropped puyos, then the loss of possible chain length, and finally the loss of winning probability. There are some other factors to make a time loss:

– Elimination of puyos: Especially, beginners tend to eliminate four puyos which seem to be useless for chain, but this elimination sends almost no garbage puyos, decreases the resources, and produces a time loss equivalent to about one move. Longer chain also needs



Puyo Puyo, Fig. 4 Examples of 5-chain variations. (**a**) is the base called 3-1 stairs, (**b**) is the variation, (**c**) is called sandwich, and (**d**) is called GTR

Puyo Puyo, Fig. 5 Examples of 11-chain by transition



longer time; this is an important factor to be discussed in the next section.
- Drop of garbage puyos: One or two garbage puyos are not so disturbing the preparation of chain, but the dropping produces a time loss equivalent to about one move. Then it is valuable to cancel completely the opponent attack even in the case of smaller attack.
- Separation of puyos: When the operated puyos are separated (Fig. 1d), unignorable time loss is produced. Generally, fine ordered shape such as Fig. 4a requires more separations and then other shapes such as Fig. 4d can be selected to reduce the separations.

Timing of Attacks

Assuming the case that player A can execute 11-chain and player B can execute only 10-chain by some delay or unlucky, it is even not preferred for player A to execute 11-chain immediately. Finishing 11-chain requires a long time so that player B can drop over 20 puyos; so probably player B can counter by 12-chain or more. Except the case where a very long chain can be luckily constructed very effectively, the first attacker of long chain is disadvantaged.

For forcing the opponent to execute the long chain at first, it is a frequent tactic to prepare and execute "secondary gun" of about two- to 4-chain separately from main chain (primary gun). There are some possible reactions for the opponent against this fast and medium attack:

1. Nothing: When the preparation of long chain is too effective, often many puyos are required to start and counter against fast attack may be impossible. Then usually preparation with less weak point is needed, and also preventing the opponent from too effective preparation is needed by checking.
2. Receiving the attack: When the attack is smaller, such as plain 2-chain producing six garbage puyos, sometimes it is better to receive the attack as is. The receiver suffers six garbage puyos, but the attacker lost eight puyos as resources and some time to eliminate them.
3. Countering by the primary gun: Assuming the case the receiver has 11-chain as his primary gun, and the attacker executed 4-chain; probably the attacker's primary gun is about 7-chain, considering the amount of resources. It is not so easy to expand 7-chain to 11-chain or more by using the expected time for finishing 11-chain counter. So, the counter by the primary gun can be the best way in some situations.
4. Countering by small attack: When the counter by the primary gun seems to be not good, it is often done to counter by secondary gun or a part of primary gun. In addition, 4-chain against 2- or 3-chain can be a good counter to press the opponent to start the primary gun. "Secondary gun war" keeping primary guns is typical among expert players.

Such tactics for timing of attacks are based on the observation of the opponent board. Players are requested to play rapidly, to observe accurately, and to change the tactics depending on the situation.

Related Works

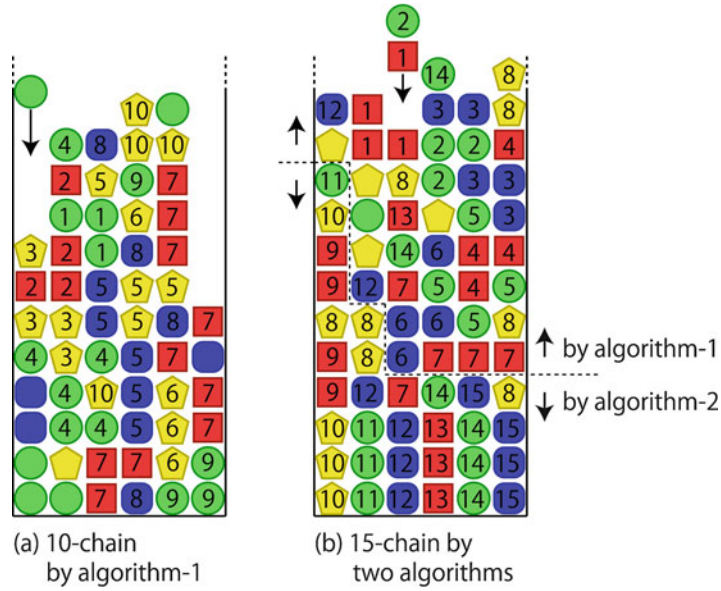
Main participators of Puyo Puyo may be publishers, players, magazines, shops, video game arcades, or competition organizers. But there are some approaches from different positions.

Analysis

As chain preparation is the core issue in Puyo Puyo, the complexity of it has been often discussed. For example, it was proven that the complexity to find the maximum chain length (when the colors of given puyos are known) is NP-complete (Matsukane and Takenaga 2005). Also the complexity to judge whether all puyos can be eliminated was proven to be NP-complete. Such facts are not important for real battles but attracted much attention as academic works on this very popular game.

Chain Construction Algorithm

According to the randomness of given colors and the complex elimination rules compared to Tetris or Dr. Mario, it is not easy to make an algorithm to



Puyo Puyo, Fig. 6 Chains generated by two algorithms

construct long chain. For a long time, computer players of official titles could execute only about 5-chain at max and they are not good rivals of intermediate or higher players.

At 2012, two algorithms for constructing long chain such as 11-chain were published (Ikeda 2012). The first algorithm extracts all possible future states after the next three moves and selects the move which can cause the biggest attack at depth 2 or depth 3 node. Figure 6a is an example of 10-chain by this algorithm. In order to improve the efficiency, second algorithm utilizes the "regular forms" developed and used by human, through tree search and matching evaluations. Figure 6b is an example of 15-chain by two algorithms.

Playable Clones

There are many official/unofficial clones for Puyo Puyo. By using them, many battles among humans via the Internet have been done, and many competitions among computer programs have been held like as the StarCraft case (see ▶ "StarCraft Bots and Competitions"). As there are many strong computer programs whose algorithms are nondisclosed, in such programs not only preparing chain but also tactics described in 3.3 seems to be well managed. For example, at 2012, a strong program "Niina" played against three strong human players and won 150 games in 217 games (http://sengiken.web.fc2.com/html/AI/vsAI201205.html (in Japanese)).

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Puzzle Game

▶ Gardenscapes and Homescapes, Casual Mobile Games

Q

Quadruped Robot

► Virtual Reality and Robotics

Quality Assurance-Artificial Intelligence

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Synonyms

Automated testing; Bug detection; Game balancing; Software testing

Definition

Quality assurance (QA) verifies that product performance and functions meet specifications. Quality assurance-artificial intelligence (QA-AI) refers to the method of AI used for QA or the program or service using that method.

Introduction

Digital games increase in complexity year after year. Additionally, the burden on QA of work such as error correction and game balance adjustment has also increased. There are various methods for QA; however, one of the most fundamental actions is playtesting games. Content adjustment and debugging work are both performed frequently from the early stage of development to the final stage. Although there is no doubt this is important work, games developed in recent years have increased in complexity making it difficult to achieve sufficient number of trials by humans alone. Therefore, research on automatic play using AI agents is becoming more popular year after year.

AutoPlay has long been the subject of research as a method of creating opponents and allies for humans. When using an exploration method, it is naturally necessary for an opponent in the game to have a certain degree of strength, but it is also necessary to make adjustments, such as restricting the opponent or ally's strength or ensuring that tactics are taught to the player. This is simpler for the agents used in QA since it is not necessary to consider such entertainment value. For example, in order to find a factor that breaks the balance of strength, it is necessary to create an agent that pursues only strength, without adjusting strength at that time. Accordingly, it is highly likely that agent creation methods for more sophisticated game contents can be applied

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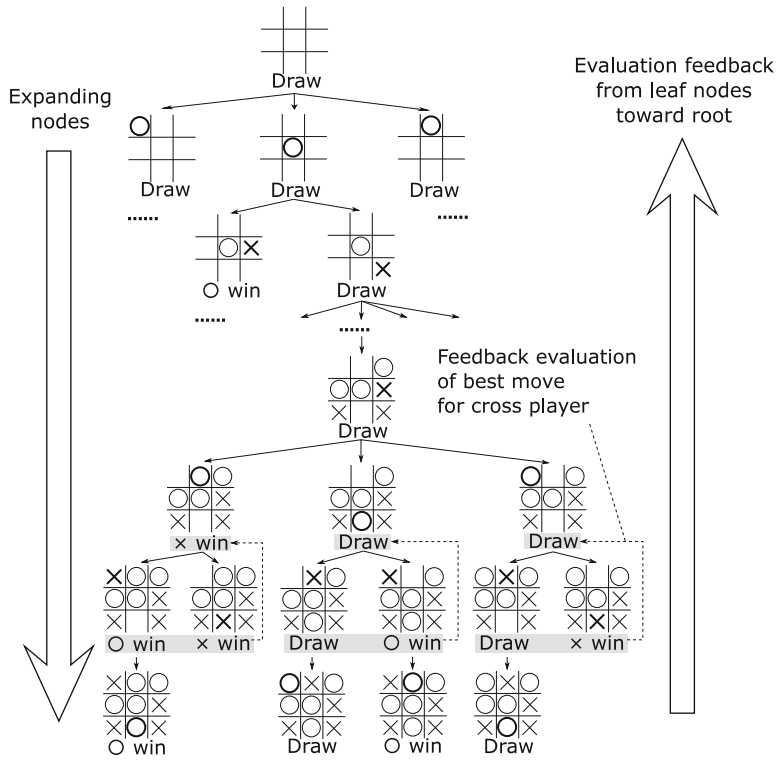
for creating QA agents. Best method for player agents changes depending on type of game, degree of freedom of player, goal that agents should reach, development environment, updating frequency, budget, and other factors.

In this section, we will cover various creation methods and actual examples of player agents that may be useful for QA, irrespective of their original purpose and focusing reasons of their adaptability. Game tree search and Monte Carlo tree search are effective for creating player agents for games with small state spaces. Character AI can create agents that are easily customizable in detail in exchange for flexibility for unknown environments. Genetic algorithm is well suited for searching for the best combination among a vast array of choices. Neural networks and Neuro Evolution of Augmenting Topologies are often used when the state space is large. Reinforcement learning is useful when one wants to focus on adaptation to an unknown environment. Reinforcement learning can be combined with NN and DNN to deal with larger state spaces.

Game Tree Search

A game tree is a non-cyclical, directional graph of state transitions representing game states as nodes and edges as actions for changing states. By searching a game tree, it is possible to arrive at the action that should be selected in the current state. For example, the game tree for *Tic-Tac-Toe* would be as shown in Fig. 1. Here, omissions are indicated by ellipsis. This tree is obtained by recursively repeating the process of expanding child nodes by the number of possible actions from the root node in the current state until there are no more nodes that can be expanded. However, if there are nodes that are effectively in the same state, the number of nodes to be expanded can be suppressed. In this figure, taking into account rotation and symmetry, the first player can only take one of three actions. In the case of *Tic-Tac-Toe*, when all the nodes are expanded, the terminal leaf node always results in a victory of one player or a tie resulting in an evaluation value. Each player can determine the evaluation value of the parent nodes based on the policy of selecting



Quality Assurance-Artificial Intelligence, Fig. 1 An example of an expanded game tree in tic-tac-toe

the best move for themselves; thus, the evaluation values can be given to all nodes toward the root node. Based on these evaluation values, the agent can select the next action.

In games such as *Tic-Tac-Toe* and *Othello*, it is possible to create a very strong agent by searching the game tree (Russell and Norvig 2009). Deep Blue, which beat the world champion at chess in 1997, also uses a game tree search (Campbell et al. 2001). Since Tic-Tac-Toe has a small board, it is not difficult to describe all states. However, for general games, node creation must be aborted part way through the process due to processor and memory constraints. For that reason, how accurately an agent can evaluate the state of an unfinished game determines its intelligence. For example, in *Othello*, there are distinctive features on the four corners and sides of the board, making it easy to evaluate properly even if the game state is not the end state. Therefore, it is easier to make a strong agent. On the other hand, *Go*, which belongs to the same category of board game, has a large board and only small differences of position unlike *Othello*. It does not have various pieces unlike *Chess*. It is difficult to make strong agents in such games that have many candidate moves and few strong features in their states for simple game tree search (Sei et al. 2005). Pruning such as by Alpha-Beta Search (Schwab 2004), which does not create unnecessary nodes for best move selection, is a method of improving the game tree search. In addition, in the event a sufficient number of states cannot be expressed after pruning, methods such as a Monte Carlo Tree Search exist whereby state is evaluated by cutting off node creation at a certain depth and conducting a simulation thereafter.

Monte Carlo Tree Search

The Monte Carlo method is a random sampling algorithm for estimating an amount that is difficult to strictly calculate. An approximate solution is obtained by generating many samples including random numbers. A Monte Carlo Tree Search (MCTS) is a search method that applies the Monte Carlo method to a game tree search (Coulom 2006). As described in the previous section, when a game tree cannot express all states, the strength of an agent is determined by how accurately it can evaluate the state of an unfinished game. MCTS is a method of estimating the evaluation value of an intermediate state using a large number of simulations including random numbers. After creating an appropriate number of nodes (generally a few to several dozen moves from the current state), the evaluation value of the state is obtained by following a certain policy to the leaf node and conducting a simulation after the leaf node (referred to as a rollout or playout). Although there are many variations for rollout policy, they all contain probabilistic calculations. In order to obtain a more accurate evaluation value, it is necessary to perform the rollout many times using more computing resources.

Although MCTS is primitively not suitable for problems that have many numbers of states, it is possible to apply to them by reducing the number of states in some way. For example, Ikehata and Ito created discrete states in *Ms. Pacman* (from Namco in 1981 (Ikehata and Ito (2011)), an action game in which the aim is to eat all the dots on the map while avoiding enemies, by dividing the map by the cross points of the route and using MCTS to create an agent (Ikehata et al. 2011). They searched more efficiently and obtained a score much higher than the world record at that time by switching the directive between "survival" and "eat" based on the results of the MCTS. Gosling and Andruszkiewicz used MCTS to select the appropriate strategy in the real-time simulation *Total War: Rome II* (from Creative Assembly in 2013 (Gosling and Andruszkiewicz, 2014)) and created a campaign AI. In doing so, they compiled an enormous number of actions into a meaningful task sequence and made it higher dimensional.

MCTS can generate all possible actions in arbitrary states and can be executed in just a simulation environment. Although it is a problem to need calculation resource, the constraint is not so strict for QA agents unlike the previous two examples that execute on runtime environment. Parallelization will be great help to accelerate it because simulations run independently. Also,

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since the search is performed in runtime, it has the benefit of being unaffected by game updates and other changes. On the other hand, it is difficult to debug and adjust hyperparameters. They are common problems with probabilistic methods.

Character AI

There are several widely known methods for making characters act as enemies or allies in a game. These include state-based agents, which are created by describing the state, actions taken in each state, state transition conditions, and goal-based agents. The behavior of goal-based agents is defined as a set of hierarchical goals (Buckland 2004). If agents can be created using such character AIs, it becomes possible to create a test agent that can be made to repeatedly take determined actions.

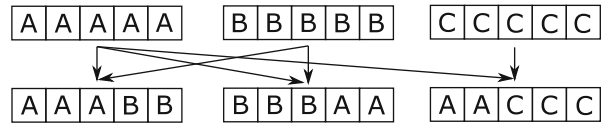
For the *Yakuza* series from Sega Games a test was conducted using a rule-based agent created by describing the preconditions and actions to take when the conditions are met. The system secured numerous calculation resources at a low cost and conducted builds and tests automatically using computers after the developers returned home. Having started with a simple test, such as a collision error check, it is now possible to perform more sophisticated error checking. It is possible to complete the game while switching modes depending on the game situation. Likewise, for *Horizon Zero Dawn* (from Guerrilla Games in 2017) an automatic test was conducted using agents that take simple actions. By running 24 h, 7 days a week test, a wide map of the open world was covered (Barbuta 2018).

Because many methods of Character AI were originally developed as game content, they have historically commonly constructed in a deep part of the game-system architecture. It needs re-implementation according to specification updates and it is difficult to use the same code for other games. However, it does not need much time to implement an executable first version. In addition, it is possible to customize even small behaviors. These features indicate that Character AI is a suitable method in the middle of development phase where its specifications can change daily. Doing many unit tests that rely on the game content is also a good practice for Character AI.

Genetic Algorithm

A genetic algorithm (GA) is a technique that mimics the evolution of living organisms and is used for combinatorial optimization problems. Learning is carried out by having solution candidates compete (Luger 2002). Solution candidates are called individuals and are represented by gene sequences. One gene represents one parameter. After randomly generating a plurality of gene sequences, the GA cuts the sequences at one or more randomly determined points and reconnects them. The evaluation value for the problem, or "fitness value," determines whether an individual is used for this crossover processing. In this way, only excellent genes pass on to the next generation and the sequence is gradually improved. Figure 2 is an example of a crossover where the good fitness values were in A, B, C order. The better the fitness value of the individual, the higher the possibility that many genes will be passed on.

In *Astronoka* (muumuu 1998), enemy characters evolve by GA. Players set traps and the characters that clear them to remain and proliferate (Morikawa 1999). Therefore, players must always think about new traps. The genes express the enemy properties and action patterns, so game designers do not have to adjust their parameters. In addition, the number of generation is adjusted dynamically to keep the improvement of the fitness value at a constant speed. GA meets the *Astronoka* game design specification that requires



Quality Assurance-Artificial Intelligence, Fig. 2 An example of Crossover

created agents to behave in response to the players' actions.

In *City Conquest* (from Intelligence Engine Design Systems in 2012), a two-player tower defense game, a stronger command than expected is discovered and the game balance is adjusted by performing a GA search of a "script" (sequence of commands) issued by the players (Champandard 2012). In this game, when the health points of one of the two players become zero, that player is defeated and the battle ends. Since the number of remaining health points of the winning player can indicate whether the battle was close, the health points are added to the fitness of the "script" of the winning player and subtracted from the script of the defeated player.

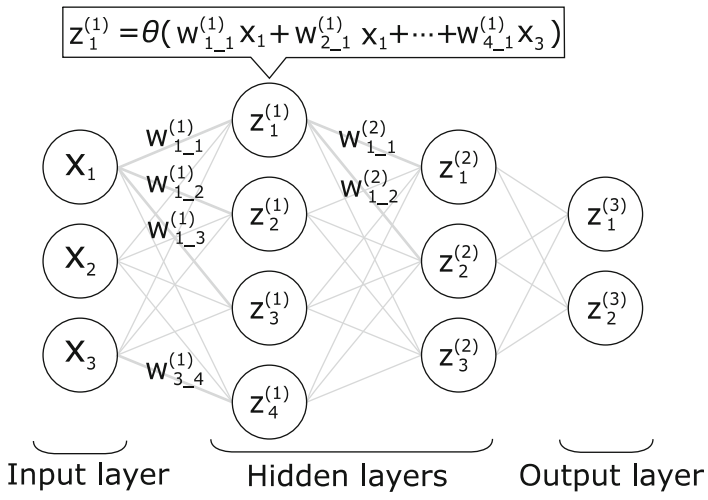
Grimms Notes Repage (from Square Enix in 2018) is a role-playing game that adopts an action battle that advances automatically. For the adjustment of the game balance, a search is performed by Genetic Programming, an expanded method from GA, to find strong party formations. Through this, pieces of equipment or characters which are overpowered can be found. For the gene structure, they used tree structure according to the party formation unlike GA that uses array structure. The difference between the remaining health points of the two players and the battle time are used for the fitness value (Manabe and Awaji 2018).

When searching in a space with many possible combinations, GA can be an option to search efficiently as long as it is possible to represent the candidates of the solution as genes. Similarly to the MCTS, it needs an exact and fast simulation environment. Also, the validity of parallelization and performance constraint is not strict if the method runs outside of the game.

Neural Networks

The human brain consists of many neurons. A network constructed by connecting neurons to each other is called a Neural Network (NN). A mathematical NN (sometimes referred to as an artificial NN as opposed to a natural NN, but we call it just NN in this section) modeled this way operates as a function that generates a unique output for a specific input. The layers between the input layer and the output layer are called the hidden layers, as shown in Fig. 3. A neural network with many layers is called a Deep Neural Network (DNN). There are DNNs often having a convolutional structure and an autoencoder algorithm. Learning that occurs using DNN is referred to as deep learning (DL).

There are not many applications in digital games of a neural network alone. In *Creatures* (from Millennium Interactive Ltd. in 1996), for which the oldest literature on the subject can be found, the intelligence of characters trained by players is formed by a neural network. Aggregates



Quality Assurance-Artificial Intelligence, Fig. 3 An example of a three layer fully connected neural network

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of neurons are called "lobes" and the neurons of respective lobes are connected (Grand et al. 1996). In addition, in *Black & White* (from Lionhead Studios in 2001), players can also raise creatures. A simple perceptron is implemented for the creature and the player can teach behavior by stroking or scolding it (Evans 2002). In the real-time strategy game *Supreme Commander 2* (from Gas Powered Games in 2012), the reaction when a platoon encounters an enemy unit is controlled using two-layer NN (Robbins 2013). As the input values, they used the number of enemy and ally units, life points, overall damage per seconds (DPS), moving speed, defensive strength, and other values which are expressed by numbers from 0.0 to 1.0. The action evaluation was calculated depending on whether their life points, DPS, etc. were improved or not after the actions. They used different NNs for four types of platoons in the game: land, naval, bomber, and fighter. In the result, each NN acquired personality. The training took about 1 h for each NN with 34 input nodes, 15 output nodes, and 98 hidden nodes. NN can be a solution to create a simple agent that reacts against inputs in a problem that allows only short training time.

Neuro-evolution of Augmenting Topologies

Neuro-evolution of Augmenting Topologies (NEAT) is an evolutionary technique that uses genetic algorithms to determine the weight and structure of connections (Stanley and Miikkulainen 2002). In *Final Fantasy Record Keeper* (from Square Enix and DeNA in 2014), NEAT was used to create a test agent for battle. The behavior of the agent in a battle is determined using a NN. As a result of learning, an agent was created that closely resembles a human being and takes a significantly tactical approach to the battle (Tomobe and Handa 2016). Adjustment of hyper-parameters of NN needs skill and it generally requires considerable time. Automated adjustment such as NEAT helps save time. However, it needs initial cost to create the structures and more computing resources to run simulations instead. Automated adjustment would work efficiently for rather large NNs.

Reinforcement Learning

Reinforcement Learning (RL) is a generic term for learning methods that carry out learning autonomously based on experience. The most common form of RL has three components: a search strategy that tests various actions, a reinforcement function that feeds back based on the rewards of the action, and a learning rule that connects the two. Historically, Microsoft Research investigated reinforcement learning of characters using their own fighting games (Graepel et al. 2004).

Shin Megami Tensei Liberation Dx2 (Sega Games 2018) supported map creation using Q-learning, one form of reinforcement learning (Matuda 2018). In the game, points are necessary to walk the map depending on the number of steps; therefore, the number of steps required for a map search must be estimated. Accordingly, the number of steps necessary for an assault was measured by making an agent, created using Q learning, walk the map with conditions added, such as passing a treasure box.

RL can search unknown environment autonomously using a reward policy against the environment. In some cases where the number of steps before a reward is too large, or there are too many branches, RL cannot search well. It needs some improvements, for example, giving a milestone reward, shorten the number of steps to get a reward, abstracting common sequence of actions into behaviors, or dividing large maps into smaller area explored only once.

Neural Network and Reinforcement Learning

In the card game *Race for the Galaxy* (from Temple Gates Games in 2017), an in-game battle agent was created by combining RL and NN (Duringer 2018). Two types of NN were separately prepared, one for evaluating the board and one for predicting the behavior of the opponent. These were

further divided into those for each expansion pack and instances where the number of battlers is "two" or "three and more." Several dozen NNs were trained in total. All inputs to those NNs were the same and board information such as deck information and whether special cards are included in the hand was used. An RL mechanism which backpropagates given rewards in the end of the games was used for the NNs and learning was carried out by self-play.

Unlike simple NN, RL is capable of learning long-term strategies by using longer state transition for learning. On the other hand, as mentioned in an earlier section, it needs some improvements if the number of steps to get a reward is too large. The learning time tends to be longer than simple NN. Therefore, RL would be cut out for games in which the update intervals are long.

Deep Reinforcement Learning

A combination of DNN and RL is called Deep Reinforcement Learning (DRL). In particular, a method using Q-Learning as a reinforcement learning method is called a Deep Q-Network (DQN). In DQN, the action value function of Q-Learning is replaced by a deep neural network.

DeepMind, which developed DQN, used a DQN in 49 2D *Atari* 2600 games and created an agent with only images as an input (Mnih et al. 2015). As a result, the agent outperformed conventional machine learning methods in 43 games and exhibited performance better than a human in 29 games. In addition to 10^120 deck compositions, *Othellonia* (from DeNA in 2016), which is a game that combines *Othello* and a card game, is a very complicated game in which the opponent's hand is invisible and combines elements such as strong randomness in the hand dealt. To manage this complexity, DeNA created a test agent using a DQN (Okumura 2018). In this scenario, the input is the board condition and the hand. That information is compressed using feature learning in order to input the status of the cards held, for which there are over 2000 kinds. Typically, the cards are expressed by one-hot vector, which has a single activated bit whose location shows its card type and inactivated bits fill the others. It means that the length of the vector must be 2000 if the game has 2000 types of cards. In addition, the length increases when a new card type is added. Feature learning in the game makes it possible to express all the cards with short vector of size 5. The data compression promotes the speed of the DQN learning. This agent showed an average win rate of 90% against the existing rule-based agent for the same deck.

In a NN, connection weights are often adjusted based on training data, but in reality, there may be no training data and we may want to create an agent for an environment that is unknown in the first place. Since a DQN automatically adjusts weights by self-simulation, it is useful for learning in such cases. However, setting the value function to an NN often does not work well. The true performance of DQN can be deduced by adding the following strategies. Experience replay selects past experiences randomly to use for learning and use them not only once but many times. Freezing the target network stabilizes learning by fixing the old NN at the target value of TD error. Reward clipping can be applied to various problems, without adjusting hyperparameters, by unifying the scale of reward to a fixed interval such as $[-1, 1]$. Skipping frames accelerates learning by carrying out learning every four frames.

Conclusion and Discussion

We introduced various methods to create QA agents as a representative of QA-AI for digital games. Although it is not limited to QA, AI for games has strict constraints in terms of development budget, man-hours, and time. Also, the specifications and the data of the games change frequently. For the latter reason, in digital games area, it is difficult to use methods that utilize big data such as supervised learning and data analysis, which show great performance in some other areas, because even if the data for the agents are collected, they become obsolete in a short time. Currently, full-scratched AI and autonomous learning or search based on reward policy are

major methods for game AI. For these methods, the higher the expression ability of the problems is, the longer learning/search time and the more difficult the control will be. It is important to select an appropriate method according to actual game development issues.

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Quality of Experience

▶ Virtual Reality: A Model for Understanding Immersive Computing

Query-by-Gaming

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Synonyms

Gaming controller; Spatio-temporal linear logic; Spatio-temporal querying

Definition

Building interfaces for a spatio-temporal query is challenging since a spatio-temporal query may require positions of specific objects in a series of

temporal instants while constructing the query. This chapter presents how gaming controllers could be used for creating spatio-temporal queries as a user plays a game. The querying engine retrieves relevant video clip segments from the database as the user controls objects by giving commands using the gaming controller. In the backend, the search engine analyzes video clips that satisfy the user's query based on the spatio-temporal logic. A sample application of query-by-gaming for tennis video games is also provided in this chapter.

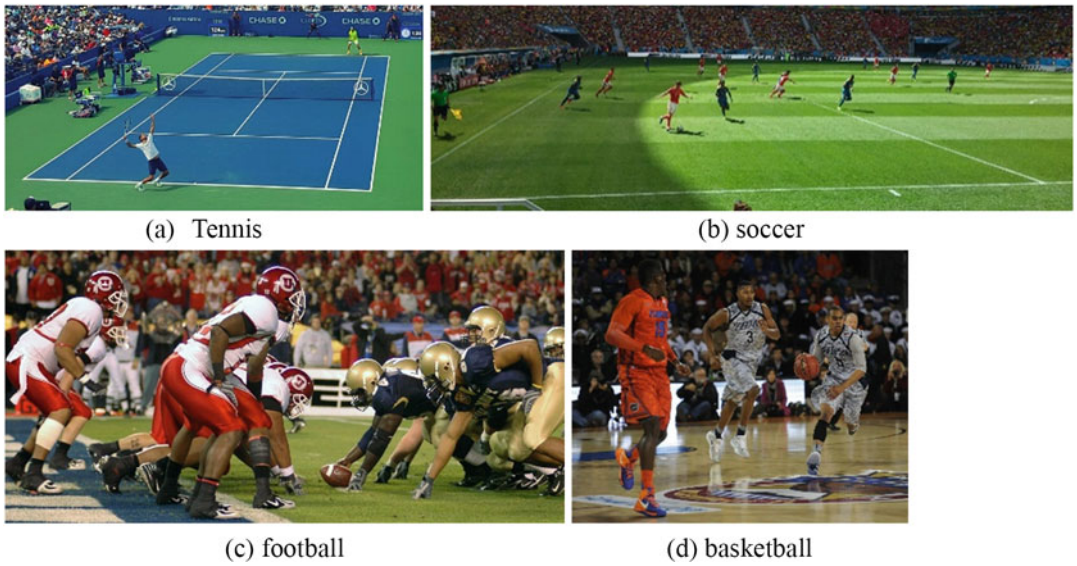
Introduction

Bridging the gap between users and database management systems require effective user interfaces. The main challenge of bridging this gap is to prepare interfaces that require minimal information to be learned about the system that executes queries. For complex querying systems beyond basic keyword search, menu-based interfaces have been popular for querying traditional relational database systems. However, building spatio-temporal queries is more complicated since these queries may involve associating locations to objects and changing positions of objects may need to be specified over a temporal interval or a series of temporal events.

A spatio-temporal query as the name implies has spatial and temporal components. For example, for a soccer video database, the query for retrieving "goals scored by Messi against Real Madrid *in the last 10 min outside the box*" has both spatial and temporal components. This query has a temporal constraint as "in the last 10 min" and a spatial constraint "outside the box." Despite being a spatio-temporal query, it does not have continuity of events. In other words, this query only checks an event that happens almost instantaneously. In this chapter, rather than focusing events instantaneously, the construction of queries that have a sequence of events is analyzed. For example, consider the query for retrieving video clips where "(i) in the mid-field, Messi passes the ball to Neymar, (ii) Neymar passes the ball to Suarez, (iii) Suarez passes the ball to Messi, and iv) Messi scores outside the box to the top left corner." To build this query, a simple, interactive, and incremental user interface would be necessary.

In this chapter, the methodology of "query-by-gaming" is explained as a way of getting input from users for constructing spatio-temporal queries. When various user interfaces for inputting data (e.g., keyboard, mouse, gaming controller, voice) is considered, it has been observed that gamers provide spatio-temporal information to the gaming engine in many game genres. Gamers control objects, move them, and generate actions based using gaming controllers. Moreover, considering the usage of technology, gaming has been popular environment not only for kids but also for old people. This observation is a motivation to use gaming controllers for spatio-temporal querying. Especially, for sports games such as tennis, soccer, football, basketball (Fig. 1), spatio-temporal querying could be achieved using gaming controllers.

Building interfaces for a spatio-temporal query is challenging since a spatio-temporal query may require positions of specific objects in a series of temporal instants while constructing the query. Having simple interfaces for spatio-temporal queries is desirable. This requires (i) developing a natural user interface, (ii) building query effectively in a simple way, (iii) integrating user into the querying and retrieval system, and (iv) getting user input in a seamless way. This chapter presents (i) building a natural interface by using the original video clips, (ii) using semantic sequence state graph as an indexing structure for query processing, (iii) integrating the user into the querying process by letting user play a game, and (iv) using a gaming controller for getting inputs from the user. This chapter is organized as follows. The following section briefly provides the state of the art work. Then the basic blocks of the querying system and utilization of gaming controllers for query-by-gaming are explained. Later the spatio-temporal query representation and execution are expressed. The last section provides the conclusion and discussion.



Query-by-Gaming, Fig. 1 Different sports where spatio-temporal querying could by applied. (Images obtained from pixabay.com)

State-of-the-Art Work

In terms of spatio-temporal querying, advancements have been made for developing languages to support spatio-temporal queries and enhancing interfaces for those queries. Spatio-Temporal Query Language (STQL) (Erwig and Schneider 2002) supports around 2,198 predicates about two evolving regions by extending SQL. Moving GeoPQL (D'Ulizia et al. 2012) extends Geographical Pictorial Query language and enables construction of queries by providing spatial properties of objects at different temporal layers. The temporal SOLAP (GIS + online analytical system) (Bisceglia et al. 2012) uses a temporal language named TPiet-QL in textual format. SQL-like SRQ (spatial relation query) (Della Penna et al. 2013) allows users to arrange visual objects (without temporal information). In visual graph-based query interface (Lu et al. 2014), four rectangular boxes are used to represent variables, conditions, video attributes and scenes while allowing two connections to attach to variable boxes or scene boxes. However, defining spatio-temporal queries with their interface is not an easy task for users.

Integrating time and handling temporal queries is challenging. While visual time automaton (Certo et al. 2013) supports time queries at different granularities, it requires users to know basic automata. On the other hand, multi-DST (dynamic spatio-temporal) querying system (d'Acierno et al. 2012) helps users build spatio-temporal queries by selecting multiple regions for an object with temporal intervals.

An alternative way of constructing queries is to use existing examples from the database. The query engine may build the query based on user browsing behavior (Yadav and Aygün 2009) or find similar videos to the browsed ones. The querying method using examples are usually named as "query-by-" followed by the type of the example used for querying. Pictorial Query-by-Example (Papadias and Sellis 1995), Query-by-Image Content (QBIC) (Flickner et al. 1995), Query-by-Humming (Ghias et al. 1995) (for music retrieval), and Query-By-Trace (QBT) (Erwig and Schneider 2000) are sample querying schemes of querying-by-example.

In quantizable video databases, the video could be represented a set of video instants such that missing parts could be predicted from these

instants (Jain and Aygun 2009). If the objects in a video visit the same locations, or in other words, if the spatial domain is restricted, these video databases are called recurrent databases (Naik et al. 2012). Query-by-gaming method is applicable to quantizable recurrent databases.

For efficient querying, the representation of spatio-temporal content in the database is important. Previously, a tennis video a clip was represented as a grammar-based string composed of objects, locations, and actions between them (Jain and Aygun 2008). Once a clip is represented as a string, the SQL's pattern matching could be applied for finding relevant clips. The queries are categorized into event-object-location, event-object, event-location, object-location, current-next event, projection, and semantic events. Using a menu-based system, the corresponding SQL patterns were generated. Since this system did not have an index structure, all strings had to be evaluated for pattern matching. Naik et al. (2008, 2012) proposed the semantic sequence state graph (S^3G) where states represent sets of object-location pairs and transitions between states represent semantic events. S^3G is a graph-based index where a user could start at any state (node) and traverse the graph to check if a sequence of events occurs or not. Moreover, S^3G allows to check whether a state is reachable from one state to another or not. Naik et al. (2008) used mouse interface where many windows pop up and the user had to choose the relevant positions of objects. Bettaiah and Aygun (2011, 2015) analyzed whether gaming controller could be more useful than inputting data through mouse clicks. Moreover, S^3G was improved by including the ranks of video segments in a video clip.

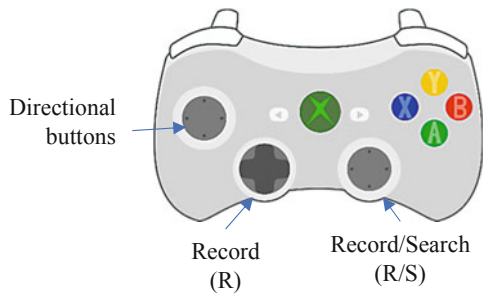
Overview of the Querying System

The querying system has two components: user interface and query processing engine. The key role of the interface is to help the user play the game with minimum intervention. As the user provides positions of objects using a gaming controller, the querying engine searches clips that are relevant to the user's query and displays the clip segment. In case multiple clips satisfy the user's query, the clip segment which appears in the same video clip as the previously displayed clip segment is given a higher priority for displaying next.

As the user provides positions of objects sequentially, the querying engine searches for clips in the system for every user query. Normally, conjunction is applied for each state provided by the user to determine video clips that satisfy all conditions provided by the user. In other words, only video clips that satisfy *all* states in the order user provides are retrieved. Hence, the number of clips that satisfy a user's query may decrease as the user increases the number of states to be satisfied thus making a stricter query. If the query becomes very strict, the system may not return any clip that would satisfy all states provided by the user. To hint about similar clips relevant to the user's query, the system also provides videos that partially satisfy the query by applying disjunction of video clips while executing the query.

Using the Gaming Controller for Querying

The user has to provide the locations of objects on the field. After selecting an object and using directional buttons on the controller, the user may assign positions to objects. Three types of button assignments are needed on the gaming controller (Fig. 2): (i) directional buttons for locating objects, (ii) recording positions of objects as a part of the query, and (iii) recording the position of the last object and then initiating search



Query-by-Gaming, Fig. 2 Assignment of buttons for querying

process. The system provides objects in an order and then the user needs to choose their locations using directional buttons. To complete the assignment of position to an object, the user presses the "record" button. The system provides the next object and so on. When the locations of all objects are determined, the user presses "the record/search" button. The major difference between "record" and "record/search" button is that "record" button does not initiate the search whereas "record/search" button informs the system that query at that instant is complete and then the system may start searching for states or video clips having objects at the corresponding locations.

Spatio-Temporal Query Representation

Let O be the set of n objects and $O = \{O_1, O_2, \ldots, O_n\}$. Similarly, let L be the set of m locations that objects could appear and $L = \{L_1, L_2, \ldots, L_m\}$. A state S is formed by a set of object-location pairs and $S = \{S_1, S_2, \ldots, S_p\}$. Whenever an object changes its position, a transition to a new state occurs. A video clip is represented as a graph of states. For example, the video clip in Fig. 3 has five consecutive states starting at state at S_1 and ending in S_5.

The states could be labeled as an initial state based on the initial positions of objects and as a final state based on the outcome. The transitions could be labeled based on the actions that cause state transitions.

Given a state graph in this form, the linear temporal logic (Vardi 2001) could be used to analyze a graph of vertices where each vertex represents a point in time. Since in this case, each temporal instant represents spatial information about objects, the spatio-temporal logic (Bimbo et al. 1995) is adapted. A spatio-temporal query can be expressed with negation (¬), disjunction (∨), conjunction (∧), implication (→), global (□), next (○), eventually (◊), until (U), and releases (R) operators as follows:

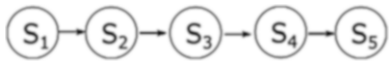
$$\Phi: = \theta \mid \neg\theta \mid \theta_1 \vee \theta_2 \mid \theta_1 \wedge \theta_2 \mid \theta_1 \rightarrow \theta_2 \mid \Box\theta \mid \bigcirc\theta \mid \Diamond\theta \mid \theta_1 U\, \theta_2 \mid \theta_1 R\, \theta_2$$

where θ, θ_1, and θ_2 are conditions evaluated at states. Negation, conjunction, disjunction, and implication operators are checked at a single state. Temporal operators (global, next, eventually, until, releases) evaluates whether a path satisfying the condition exists or not.

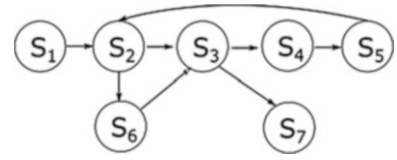
In this querying system, the most important temporal operators are the "next" and "eventually" operators. The "next" operator checks whether a specific state S_i is directly reachable from a current state S_c. The queries based on the *next* operator are named as subsequent queries. The "eventually" operator checks whether a specific state S_i is reachable from a current state S_c; however, S_i may not be *directly* reachable from the current state S_c. Such queries are named as eventual queries. Consider the state graph in Fig. 3 and assume that S_2 is the current state. For this graph, $\bigcirc\ S_3$ is true, but $\bigcirc\ S_5$ is false since S_5 is not directly reachable from state S_2. However, $\Diamond\ S_5$ is true since there is a path from S_2 to S_5.

The same state may be revisited in a video clip, and this may generate cycles of states in a video clip. For example, assume that the sequence of states is S_1, S_2, S_3, S_4, S_5, S_2, S_6, S_3, S_7 for a video clip and the graph for this clip is depicted in Fig. 4.

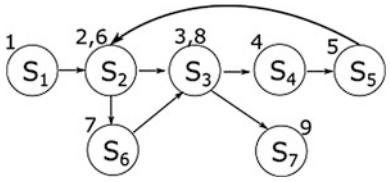
The graph in Fig. 4 returns true for the sequence of states S_2, S_6, S_3, S_7. This graph has also the sequence of S_2, S_6, S_3, S_4, although the video clip did not have these states in this order. In the video clip, S_4 is reachable from S_3 if the previous state for S_3 is S_2. If the previous state for S_3 is S_6, S_4 is not reachable from S_3 in the



Query-by-Gaming, Fig. 3 States of a clip



Query-by-Gaming, Fig. 4 Cycle of states for video a clip

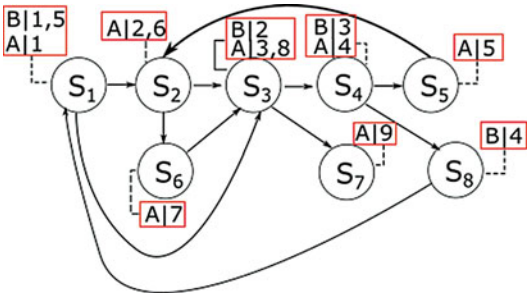


Query-by-Gaming, Fig. 5 Ranks of states in a video clip

video clip. This case shows that the ranks of states in a clip need to be maintained as shown in Fig. 5. States S_2 and S_3 have multiple ranks as they appear twice in the video clip. State S_2 appears as the second and sixth states whereas S_3 appears as the third and eighth states.

In a video database, there could be many clips that may share the same states. For example, assume that another video clip has the following states: S_1, S_3, S_4, S_8, S_1. If multiple clips are merged, the state graph loses specific information related to video clips. Thus, the ranks of states per clip are maintained. For example, if this clip is labeled as B and the previous clip is labeled as A, the state graph becomes as shown in Fig. 6.

This state graph representation can help to develop indexing for spatio-temporal querying. Semantic sequence state graph (S^3G) (Naik et al. 2008, 2012) is defined similar to a finite automata in the form of $M = [\mathbf{S},\mathbf{\Sigma},\delta,s_0,\mathbf{F}]$, where $\mathbf{S}$ is a set of internal states, $\mathbf{\Sigma}$ is a finite input alphabet set, s_0 is the initial state, $\mathbf{F}$ is a set of external states, and δ is a transition function mapping $\mathbf{S} \times \mathbf{\Sigma}$ to $\mathbf{S} \cup \mathbf{F}$. Each internal state is a set of object-location pairs. Let Σ_O and Σ_L be the set of objects and locations. Then, each object-location (OL) pair in a state S should be a subset a member of the cross product of objects and locations $OL \in \Sigma_O \times \Sigma_L$. The set of external states is optional but could be helpful when a series of states has an outcome (e.g., a player wins the points). The structure of an external state is the same as internal states. The transitions are represented with the alphabet ($\mathbf{\Sigma}$) and events caused by objects lead to transitions. In addition, each state has a set of clips. Each state also keeps the rank of each in a video clip.



Query-by-Gaming, Fig. 6 Representation of multiple clips in a state graph

Querying

Query-by-gaming has been evaluated on a tennis video database. In a tennis game, there are three objects: the ball and two players (player $_1$ and player $_2$). A state is composed of these three objects and their locations. The tennis court is divided into 13 locations based on the rules of a game (e.g., the areas where the ball must hit after a serve) (Bettaiah and Aygun 2015). Let L_b, L_1, and L_2 represent the locations of the ball, player$_1$, and player$_2$, respectively. If player$_1$ serves, player$_2$ becomes the next player and vice versa. Algorithm 1 provides the pseudo-code for the subsequent query. In Algorithm 1, Ω_C is the current state and Ω_N is the next state selected by the user. $C_{C,N}$ returns the set of clips that have both these states. $\overline{C_{C,N}}$ returns the clips where these states appear back to back using the ranks of states. Two lists are maintained as the user continues to build the query. One list ($\mathbb{Q}$) takes the intersection of all $\overline{C_{C,N}}$ to detect clips that satisfy the user's query. Moreover, the union of clips that satisfy the query at a point ($\mathfrak{V}$) are also kept.

The eventual query checks whether a state is reachable from a current state. Algorithm 2 provides the pseudo-code for eventual query. In Algorithm 2, Ω_0 is the initial state and Ω_F is the final state selected by the user for the eventual query. The algorithm first identifies whether there is a path from Ω_0 to Ω_F. For every path from Ω_0 to Ω_F, the intermedia states are determined. For each consecutive state, the clips that have both states are determined and then the ranks are checked if those states appear back to back as

```
void Subsequent_Query ( )
begin
  // L_b, L_1, L_2 represents location of ball, player_1, player_2 respectively.
  L_b ← Initial_ball_loc
  L_1 ← Initial_player_1_loc
  L_2 ← Initial_player_2_loc
  player_1_serve ← 1        // player1 serving
  player_2_serve ← 0
  ℧ ← ϕ   // List of clips having subset of the events queried
  ℚ ← ϕ   // List of clips having all the events queried
  // Play and pause the video at the first serve
  Ω_0 ← (L_b, L_1, L_2) // Initial State
  Ω_C ← Ω_0   // initializing the current state
  do          // setting the next state
    L_b ← Next_ball_loc
    if (player_1_serve = = 1)
      L_2 ← Next_ player_2_loc
      Ω_N ← (L_b, L_1, L_2)
    endif
    if (player_2_serve = = 1)
      L_1 ← Next_player_1_loc
      Ω_N ← (L_b, L_1, L_2)
    endif
    C_C,N = C_C ∩ C_N= Search (Ω_C, Ω_N) // search in S^3G for transition from Ω_C to Ω_N.
    C_C,N (overline) = ClipsWithOrder (C_C,N)
    ℧ ← ℧ ∪ C_C,N (overline)
    ℚ ← ℚ ∩ C_C,N (overline)   (in the initial run ℚ ← C_C,N (overline) )
    // Play the event from one of the clips in common clips from
    StartTime to EndTime
    // Pause the video at EndTime.
    // Switch the serve
    Ω_C ← Ω_N
  until ℚ = = empty OR no gamepad input
end
```

Query-by-Gaming, Algorithm 1 Subsequent query for query-by-gaming

in the subsequent query. Fig. 7 shows the interface for tennis video database application.

Conclusion and Discussion

Query-by-gaming can effectively be used for building spatio-temporal queries and then these queries can be executed using the semantic sequence state graph (S^3G). While the user plays a game, the querying system analyzes user inputs on controlling objects and then displays the video segment that is closest to what the user has provided for the continuity of the game. The search engine processes all user states and eventually presents the actual result of the user query. Moreover, the search engine also keeps the clips that satisfy the partial user query as the

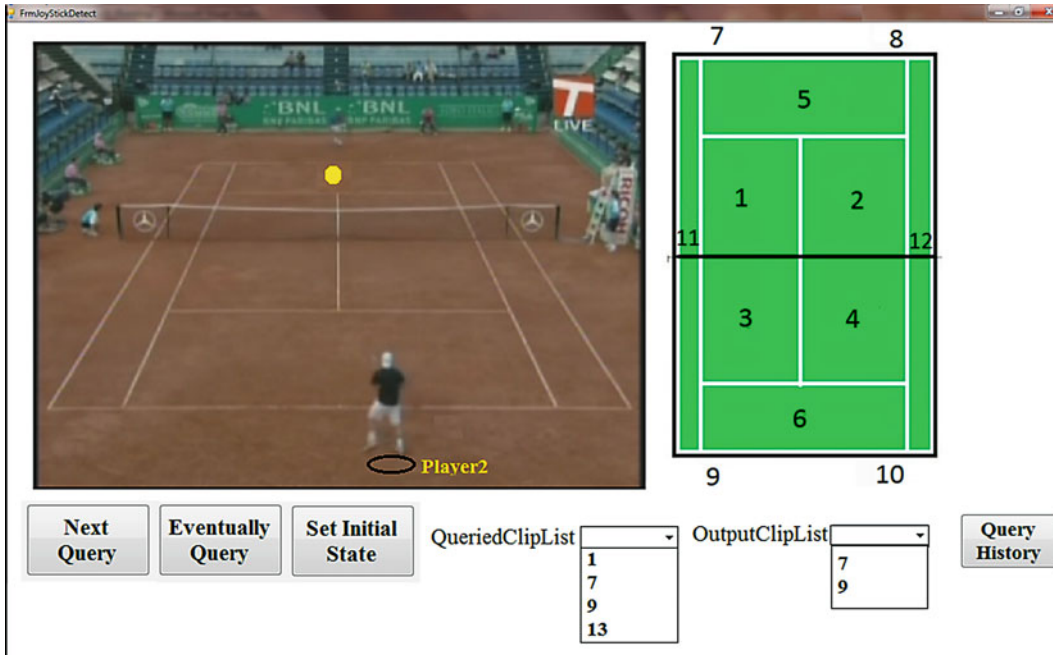
```
void Eventual_Query ( )
begin
// Ω0(Lb, L1, L2) represents location of ball, player1, player2 respectively, in the initial state Ω0
// ΩF(Lb, L1, L2) represents location of ball, player1, player2 respectively, in the final state ΩF
   // Ωa…b represents the set of intermediate states between Ωa & Ωb
   // Ωa…b[i] represents the ith intermediate state between Ωa & Ωb
   // Cp represents clips in state Ωp ;

   // set initial and final states
    Ω0(Lb, L1, L2) ← (Initial_ball_loc, Initial_player1_loc, Initial_player2_loc)
    ΩF(Lb, L1, L2) ← (Final_ball_loc, Final_player1_loc, Final_player2_loc)

    ℧ ← Ø  // List of clips having subset of the intermediate events between Ω0 & ΩF
    ℚ ← Ø   // List of clips having all the events between Ω0 & ΩF
    Initial_Present = SearchState (Ω0) // check presence of initial and final states
    Final_Present = SearchState (ΩF)
    if  not (Initial_Present)  OR  not (Final_Present)  then
          Print "Queried state/states does not exist"
    else
      Ω0…F = SelectConnectedStates(Ω0,ΩF)       // Ω0,F – Intermediate States
      if  Ω0…F = = Ø
          Print "Cannot reach the FinalState from InitialState"
      else
        for i in range( 0 to | Ω0…F|-1) : // check the ranks of clips
          Ωp= Ω0…F[i]
          Ωq= Ω0…F[i+1]
          Cp,q = Cp ∩ Cq
          C̄p,q = ClipsWithOrder (Cp,q)
          ℧ ← ℧ U C̄p,q
          if (i==0) then ℚ ← C̄p,q   else ℚ ← ℚ ∩ C̄p,q endif
        end
   end
```

Query-by-Gaming, Algorithm 2 Eventual query for query-by-gaming

query is built. S^{3}G has a low complexity for executing the subsequent query (O(1)). Semantic events or displacement of objects determine the new states. Especially, the subsequent query depends on the granularity of semantic events. Semantic transitions should be adapted carefully. Nevertheless, eventual query may always work even if the granularity of states may differ. As future work, the continuity of user playing experience could be increased. The current system currently pauses the video for the user input. As future work, the querying engine may detect movement of objects and execute queries instantly without user interruption.



Query-by-Gaming, Fig. 7 Sample user interface for query-by-gaming

Cross-References

- Scalable Techniques to Visualize Spatiotemporal Data
- Spatio-temporal Narrative Framework for Architecture in Video Games

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Ray Tracing in Video Games

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Synonyms

Interactive ray tracing; Ray casting; Real-time ray tracing; Recursive ray tracing

Definitions

Ray tracing – A rendering technique in 3D computer graphics that calculates the color of pixels by tracing the path that light would take if it were to travel from the eye of the viewer through the virtual 3D scene.

Video game – A video game is an electronic game that a player interacts with the computer using input devices such as a keyboard, mouse, game controller, mobile phone, or virtual reality headset.

Introduction

While ray tracing has been around for quite a while, it has only recently become a popular topic in the gaming community. With the recent introduction of process-effective algorithms, as well as other technologies; both software and hardware, it has become a much more viable option for rendering.

Starting with the basics, what is ray tracing? Put simply, ray tracing is a different form of rendering than what is typically used. Nvidia states that ray tracing "calculates the color of pixels by tracing the path that light would take if it were to travel from the eye of the viewer through the virtual 3D scene" (NVIDIA RTX Ray Tracing). In most use cases, this is impractical and time consuming due to an extremely large number of calculations. Because of the impracticalities of ray tracing, games require an entirely different rendering, a process known as rasterization. According to Michael Worboys (Worboys 2003), rasterization is a process where upon rendering 3D scene, triangle polygons which are translated to pixels on the screen. Though rasterization is far more efficient, it also has its drawbacks. Models must not be too detailed or the rasterization process takes longer, which is highly undesirable where 30 frames is a gaming community accepted standard minimum number of frames per second, disregarding stylized games which are intended to render otherwise.

Ray tracing in real-time was once thought to be the epitome of rendering hardware capabilities. This is because of how exactly ray tracing works. Ray tracing is when each pixel on the screen projects a line called a "ray" into a 3D-modeled scene. Each of these rays bounce off objects in the scene a specified number of times, gaining lighting and color information at each collision (NVIDIA RTX Ray Tracing). Due to the number of pixels on screens, the already intensive calculation process needs to be calculated over 2 million times per frame at a standard 1080p resolution. With a minimum of 30 frames per second, the math very quickly adds up. Ray tracing has been around for a long time now, however until recently, the renders could take hours for a single frame. Due to this, ray tracing was generally only used in film for special effects.

Graphics Hardware

The entirety of the gaming industry has primarily built hardware as well as software focused on the rasterization techniques that are now considered common practise. Due to the complex mathematical calculations, most of today's hardware is not suited for ray tracing. With the primary industry focus currently turning to ray tracing, old hardware is soon to become obsolete. While this is nothing new with computer electronics, older graphics cards were still able to be utilized over a long period of time due to a downgrade in graphics quality; however, with the introduction

of ray tracing, and the intensive calculations that come with it, this long period may become an abrupt wall of inaccessibility to the majority of hardware, currently in use by consumers.

Questions to Be Answered

Main Question How will the older generation of comparable graphics hardware perform when compared to the newer generation hardware built for ray tracing acceleration in a 3D modeling environment?

Secondary Question How will older and newer graphics cards compare when utilized in a game design environment as opposed to a 3D modeling environment?

Hypothesis

Hypothesis One As is typical of new hardware, the older generation of hardware will fall short when compared to the newer generation of graphics cards. The newer graphics card will increase performance by a substantial amount when measured in the same environments.

Null Hypothesis One The older graphics cards will hold their own when compared to the newer iterations of the same cards. Both cards will perform similarly overall when measured in the same environments.

Hypothesis Two When rending the same scene in a game development environment, the older graphics cards will fall behind in performance. The frame rate of the older graphics card will enable the scene to be unusable to effectively play, while the newer graphics card will show signs of playability.

Null Hypothesis Two Neither graphics card will render the scene efficiently. The scene in a video game environment will be totally unplayable. Unplayable in this instance refers to a frame rate well below the 30 frames per second previously discussed.

Terminology

Rendering – The generation of a two-dimensional or three-dimensional image from a model by means of application programs.

Ray tracing – A rendering technique in 3D computer graphics that calculates the color of pixels by tracing the path that light would take if it were to travel from the eye of the viewer through the virtual 3D scene.

Rasterization – Rendering an image via triangle polygons, which are translated to pixels on the screen.

Game industry – A catch-all term for any company or industry which has a stake in gaming as an industry. This includes, but is not limited to: graphics card manufacturers, video game console developers, and video game developers.

Hot-fix – A quick patch or update to fix a specific issue in software. These are generally used to fix bad software until the next major update is released.

Polygons – A flat plane made up of 3 vertices'.

Vertices – A point in a 3D environment. Two vertices make a line, and three make a face/polygon.

Ray casting – A process of using a straight line to check collision with objects in a scene.

Mechanics – A term used when referring to a component of a game which the player is able to utilize for one reason or another. E.g. jumping, climbing, and swimming.

Cost – The processing power required for a single task.

Frame rate – The speed at which frames update on the screen, typically calculated in Frames per Second (FPS).

AI – Artificial Intelligence.

Image noise – Unwanted artifacts in an image, typically only a few pixels large. This can also be referred to as "grain."

Post-processing – Manipulation of an image after it has been created.

Scene – A group of 3D models used to represent a digital environment.

Spatial volume – An allocation of space within a 3D environment.

Color bleeding – A slight reflection of color from objects which are adjacent.

Subsurface scattering – The manner in which light enters a translucent (semi-transparent) object which is then scattered or reflected.

Subdivide – Dividing polygons into more polygons. (ex. 1 polygon becomes 2 when subdivided 1 time).

Orthographic – A 2-dimensional representation of a 3-Dimensional object or space.

Perspective – A view from which shows height, width, and depth to accurately portray 3-Dimensional space.

Sample rate – The number of times a section of image is refined while rendering an image.

Material – An object surface data which tells the renderer how it should appear (ex. Metallic rough, or metallic reflective).

Review of Literature

The base principal of ray tracing has been around since the early days of 3D games; one of the first being "Wolfenstein 3D" by *ID Software* (Softworks 2012). *Raycasting* uses the same principals as ray tracing to calculate physics, and is currently utilized in countless games for *mechanics* based around physics, such as firing a weapon, or even calculating jump physics. These rays are used sparsely due to the cost of calculations. In practise, these rays are currently utilized hundreds of times a minute without much of a change in frame rate. The reason these are able to be utilized without much of a change in frame rate is because they usually only need a single collision. When compared to ray tracing, which always uses at least 1 bounce, requiring 2 rays; one to geometry and the other from geometry to the light source, the difference becomes apparent. This is why ray tracing was not viable until recently. Although noise and quality are greatly improved with more bounces, as the number increases so does the computational power necessary (NVIDIA RTX Ray Tracing).

Recent developments in software AI and recursion algorithms have enabled the Computer Scientists at Nvidia to create what they call an "AI-Accelerated Denoiser." What this does is takes image noise in and matches those pixels to the surrounding image to create a clearer image (Nvidia Turing 2018). More recent graphics cards produced by Nvidia are equipped with AI acceleration capabilities in the form of "Turing Tensor Cores" to assist in these de-noising techniques for use in combination with ray tracing (Nvidia 2018). With these AI techniques, the number of bounces each ray has to do is theoretically capable of being reduced to its absolute minimum of 1; however, the quality of image is greatly improved, even increasing that number as the AI has more to work with when creating the cleaner image. After the image is rendered, de-noising occurs during the post-processing stage before it is shown on the screen. This process is further expanded upon by a process called Deep Learning Super-Sampling (DLSS) if ray tracing is being performed on Nvidia RTX card. DLSS essentially takes pre-calculated improvements to visuals and applies them to the ray tracing process, allowing an increase in frames per second (Nvidia 2018).

As it stands, Nvidia appears to be the leading authority in ray casting due to the amount of information readily available, however; AMD, another authority in ray tracing technology, seems to primarily use a technique called Bounding Volume Hierarchy (BVH) to accelerate Ray Tracing. Through segmenting a scene dynamically into spatial volumes, the required data to calculate each ray is reduced (AMD Radeon ProRender).

Difference in Quality

The largest difference between rasterization and ray tracing is that as you increase polygons in a rasterized scene, the computational power necessary also increases (Worboys 2003). In ray tracing, the main computational increase primarily occurs when the number of ray bounces is increased; however, this does not mean that

polygon count is ignored as the more polygons; the more complex the bounces need to be to render the image. This means that while tricks can be utilized to create insane levels of detail with rasterization, they would not be as necessary with a full ray tracing rendering system. Color bleeding and subsurface scattering are also traits which are time-consuming to create with rasterization but are inherently available with ray tracing (Nvidia 2018). These are created naturally by the bounce process of ray tracing and create a much more realistic and immersive look for games.

Methodology

With the industries focus turning to ray tracing as a standard for graphics rendering, the graphics hardware consumers currently going to be obsolete at a much quicker depreciation rate. Due to the complexities noted earlier in this article, current hardware may not be able to handle the changes to come; at least not nearly as well. Thankfully, the graphics and gaming industry has gone through changes like this before, which can be examined and compared to this change in the industry.

The examination can be conducted in two stages. The first stage is based on an experimental build (v. 2.82) of Blender (Blender.org), which was used to construct two different 3D scenes. The experimental build was decided upon due to the lack of compatibility for utilizing the turing cores in the officially released version as of the writing of this article. All stages were run on two different generations of graphics cards with the same performance level for a better comparison. The GTX 1060 represents the lower-end graphics card, and the RTX 2060 represents the higher-end graphics card.

The first of the two scenes constructed was a plane subdivided, so it contains 1,048,576 faces. The vertices' heights were then randomized based on a noise image generated in Blender. This gave the plane details such as shadows and depth. A material resembling hard plastic was then applied to add complexity to the render. This was then rendered in a 4 K × 4 K resolution (4098 × 4098) orthographic perspective top-down view. This same scene was then rendered from a perspective viewpoint originating from a corner of the square in a typical 4 K configuration (4098 × 2160). These renders were then rendered multiple times using different sample rates to find the sample count, where increasing said count any further would not return any better results. After the optimal sample count was found, the scene was rendered from each perspective for a final time on each graphics card, and the time to render was recorded based on the graphics card utilized.

The second scene was created by adding in more complex effects such as water reflections as well as transparency to various objects. Its polygon count was higher as well, sitting at around 6.6 million polygons. This scene is referred to as the island scene, as the focus of the scene is a lone volcanic island covered in stones, grass, and palm trees, which is surrounded by an ocean. The ocean adds an additional complication as it is rendered by altering how the rays reflect off of the surface of the water throughout the 5-second animation. The first frame of The island scene was used as a reference point when comparing the render times to the full rendered animation. The render times for both the single frame and the full animation were recorded for each graphics card, and this concluded the first stage.

The second stage takes the island scene and places it in an experimental build of the Unity3d Game Engine (Unity.com). Again, the experimental build (v. 2019.3.0b8) was chosen due to ray tracing being inaccessible in earlier versions. After importing the 3D models for the environment and recreating the scene as it existed in blender, the materials for every object had to be recreated for unity. After the scene was complete, it was run on both graphics cards. A script was then implemented to calculate the average frames per second; this is the data which was recorded. As a final step to challenge the existence of ray tracing in gaming, the scene was optimized by cutting the polygon count in half to about 3.3 million, and the frame rates were re-recorded.

This optimization was made because the polygon count in games tends to be highly controlled based on various conditions, and the high polygon count used in the blender scene does not accurately represent a typical game environment's optimization. The high polygon count data is still useful as it represents an extreme use case of a non-optimized game environment, which occasionally happens. All data collected using the methods described were then compared and analyzed in the following sections.

Data Analysis

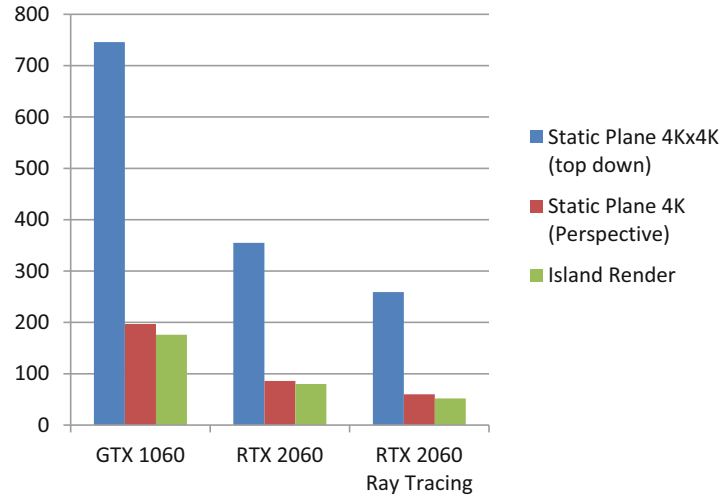
The collected data is intended to test the reliability of ray tracing in game design. With the standard of rasterization in video game rendering closing the gap between digital and reality, is Ray Tracing the next stage of graphical processing in gaming?

There were two main stages. The first stage explored the 3D environment blender for rendering scenes and animations at various levels of detail and comparing the render times. Each scene in the blender is progressively more complex with the amount of detail involved in rendering the scene. Each render's details were recorded, as well as how long the scene took to fully render. The purpose of this stage is to set a baseline with which the second stage can be compared to, as ray tracing has been utilized in rendering and animation for videos and films for some time.

To begin, Fig. 1 shows the render time of the static images in seconds. This data indicates a decrease in the time it took to render each image, additionally, all of this data was collected while rendering the scene in a ray traced environment. It is important to note that "Performance" is defined by the time it takes to render the given scenes. The GTX 1060 graphics card performed the worst between the two cards. The RTX 2060 has two different times on this graph due to it having "Turing Cores"; one measurement utilizes the cores, and the other doesn't. This shows a difference in render capabilities on the same hardware. The data marked "Ray Tracing" is utilizing the Artificial Intelligence capabilities for the rendering, and it greatly decreased the time over the GTX 1060, although the raw performance of the RTX 2060 alone was a significant increase in performance in all renders. The equation below calculated that the performance was increased by 71.03% between GTX 1060 and the basic RTX 2060 in the top-down static plane image.

$$\frac{|V_1 - V_2|}{\left[\frac{(V_1+V_2)}{2}\right]} \times 100$$

On that same render, with the turing cores introduced, the RTX 2060's performance

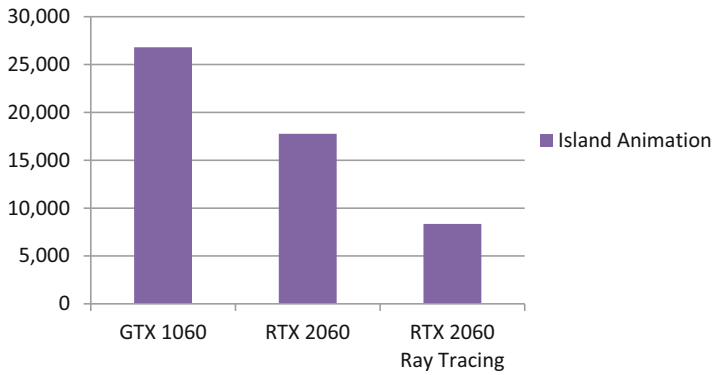


Ray Tracing in Video Games, Fig. 1 Static render times in seconds

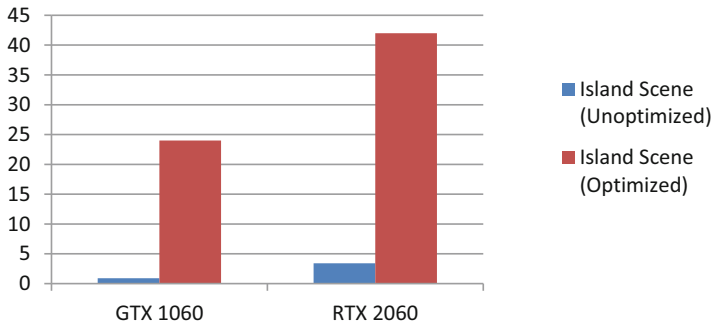
increases an additional 31.27%, creating a total performance increase of 96.92% between the GTX 1060 and the RTX 2060 utilizing the turing cores. The perspective render of the static plane boasted similar results in performance increase, with a 78.45% increase between the GTX 1060 and the RTX 2060, and an overall increase of 106.62% after utilizing the turing cores. The static island render proved to see very similar performance increases of 75% between the two base cards and an overall increase in performance of 108.77% after introducing the turing cores.

The next graph, Fig. 2, shows the differences in time for the animated island scene. Again, the GTX 1060 underperformed compared to the basic RTX 2060. The RTX 2060 had a 40% increase in performance over a total of 150 Frames in the 5-s animation. Utilizing the turing cores, the RTX 2060 increased another 72.14%. This creates an overall performance increase of 105.04% between the GTX 1060 and the RTX 2060 cards. This concludes stage one. Stage two involves running the same island scene in a Unity3D, a game engine environment while utilizing Ray Tracing.

This stage compares the frame rates in both systems under two different conditions, as shown in Fig. 3. The first condition is an unoptimized island scene, the same scene rendered in blender with minor modifications. Due to draw distances, the ocean was reduced in size as it was not fully rendered anyway. The polygon count of 6.6 million is very high for an environment in a game engine; even what is considered a "high" number is dependent on which game engine is being utilized, as well as project requirements for polygon counts. The second condition consists of the island scene, which has been more optimized to run in a game engine. By reducing the triangle count by half to 3.3 M, the results increased dramatically on both graphics cards. The results in this stage are recorded in frames per second, or FPS. The FPS count is directly related to the performance output of each graphics card; the higher the FPS, the higher the performance.



Ray Tracing in Video Games, Fig. 2 Kinetic Island render times



Ray Tracing in Video Games, Fig. 3 Game engine frames per second

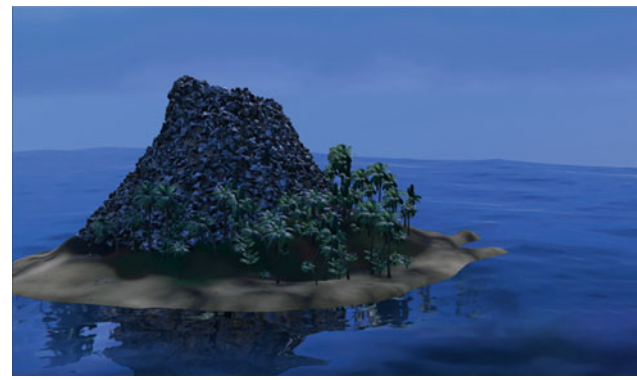
Starting with the unoptimized scene, the GTX 1060 was able to render the scene at a steady 0.9 FPS. This implies that each frame takes just over 1 s to render. Following that, the RTX 2060 was able to render the scene at an average of 3.4 FPS, or around 1 frame every 294 ms. While this does not seem like a large difference, it is a 116.3% increase in performance. In the optimized version of the island scene, the GTX 1060 rendered the scene at 24 FPS, or about 42 ms per frame. While the animation appears smooth, it is still unacceptable by most gaming standards. The RTX 2060 rendered the scene at 42 FPS for an overall increase of 54.55% in performance while taking an average of about 24 ms to render each frame.

Overall, the results drastically varied between the 3D environment results and the game design environment. While the 3D environment results are much clearer and color correct (Fig. 5), the game design environment does succeed in producing very similar results as shown in Fig. 4, although it is darker overall. The following section reviews the data collected as well as discuss conclusions and other implications (Fig. 5).

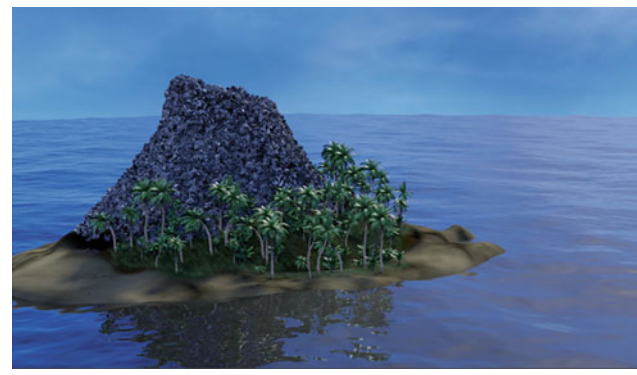
Conclusions

The initial limitation is the lack of current data. Due to the topic being so recently viable, large-scale data evaluation in the current state of the gaming industry is unavailable. In conclusion, however, the data recorded looks to be very promising overall. The data indicates large increases in performance after switching to the RTX 2060 graphics card. It aimed to test the reliability of ray tracing in game design. The render times and frame rates reveal that the performance increase from the GTX generation to the RTX generation is substantial even without utilizing the Turing Cores for enhanced Ray Tracing performance.

The first question asked how the older generation of graphics card compares to the newer generation card when compared in a 3D modeling



Ray Tracing in Video Games, Fig. 4 Unity environment first frame



Ray Tracing in Video Games, Fig. 5 Blender environment first frame

environment. In each test utilizing the 3D environment, the RTX 2060 outperformed the GTX 1060 by at least 70% before the turing cores were introduced. Upon Introducing the turing cores to enable the ray tracing Acceleration, all of the renders for the RTX 2060 saw a substantial increase yet again in performance. This data confirms the first hypothesis. The newer hardware completely outperforms the older hardware, and the turing cores add insult to injury with the extra performance boost.

The first stage tests were necessary to form a frame of reference when comparing the data to the frames per second information garnered from the game development environment. When referring to the data from the first stage, it is important to note that each frame took multiple seconds each. For the full animation of the island, 150 Frames, the absolute quickest time to render the scene was still over 2 h long, averaging about 55.64 s per frame. This exact same scene before any optimization was able to render in the game development environment at around 0.9 frames per second at best with the GTX 1060. This means that calculating each image of the animation took about roughly 1 s on average when utilizing the GTX 1060 graphics card. The performance increases to 3.4 frames per second at best with the RTX 2060, resulting in a render time of 294 milliseconds for each frame. These numbers when compared to the render times for the 3D environment show astronomical decreases in the amount of time it takes to render each frame. Neither graphics card renders the scene in its unoptimized state effectively enough to meet any gaming standards. While the RTX 2060 outperforms the GTX 1060 by 116%, it is considered to be comparable quality when compared to each other. In this instance, the second null hypothesis is the accepted hypotheses. This is due to neither frame rates being actually playable, though the image quality stays constant between both graphics cards.

The final set of data saw an optimization of the island scene. Reducing the polygon count by half, allowed both graphics cards to increase frame rate dramatically. The GTX 1060 was able to render the scene at 24 frames per second, where the RTX 2060 was able to render 42 frames per second. These numbers show that gaming while utilizing ray tracing is definitely possible. The older graphics card was able to reach 80% of the accepted minimum frame rate, while newer graphics card performed well beyond the minimum of 30. After the polygon optimization, the RTX 2060 outperformed the GTX 1060 by 54.55%. Though these optimizations did not take into account occlusion culling wherein the objects in the scene dynamically exclude themselves from being rendered when not in view to speed up render times, with further optimization it is believed that the GTX 1060 could run above the minimum frame rate. In this instance, the second hypothesis is the accepted hypotheses. This is due to the large gap in frame rate between the graphics cards. Although further optimization would better the results of both graphics cards to above the minimum frame rate of 30, the gap between the graphics cards would only grow larger as the RTX 2060 would more efficiently be able to utilize the turing cores.

This successfully tested the reliability of ray tracing in game design. Nevertheless, if this were to be performed again, some things would need to be changed. First off, all programs utilized were in Beta release, meaning they were not officially released at the time of writing this article. This means that the programs may not have been optimized or even fully utilizing the ray tracing capabilities of the RTX 2060, which could possibly skew the findings. The Beta releases were used due to lack of implementation for ray tracing acceleration in the official releases of these programs. The second thing which should change or be improved is the optimized island scene could be further optimized to better represent a scene from a game utilizing level of depth models as well as dynamic occlusion which was previously mentioned. As it stands, the scene is a good representation of polygon count in a gaming environment; however, game engines allow much more optimization, which would drastically increase all frame rates. Though the data is far from conclusive, it indicates that at the very least ray tracing in video games is a definite reality, and though the newer graphics cards will perform far better than older models, the older models may still have a

life to live as the focus shifts to ray tracing as a means of rendering.

Cross-References

► Raycasting in Virtual Reality

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Raycasting in Virtual Reality

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Synonyms

3D pointing; Distal pointing; Virtual pointing metaphor

Definitions

Raycasting is a set of interaction techniques used in immersive environments for selection of targets at the distance. Raycasting resembles real-life pointing with a laser pointer: the user points a ray of light at the target and confirms its selection with a motion gesture, a voice command, or a button click. Raycasting belongs to a family of interaction techniques known as virtual pointing. A more general term, 3D pointing, includes raycasting as one of the common approaches to selection of objects in immersive environments. The term "raycasting" should not be confused with the term used in computer graphics to describe a rendering technique.

Introduction

Object acquisition is a prerequisite for object manipulation in 3D user interfaces (Bowman et al. 2017). Target acquisition technique must facilitate the indication of an object and confirmation of its selection. It should also provide visual, haptic, or auditory feedback during the selection task. A popular technique to realize target acquisition is a family of raycasting techniques. Raycasting borrows the familiar pointing using a laser pointer adapting it for acquisition of 3D objects in an immersive environment.

The Family of Raycasting Techniques

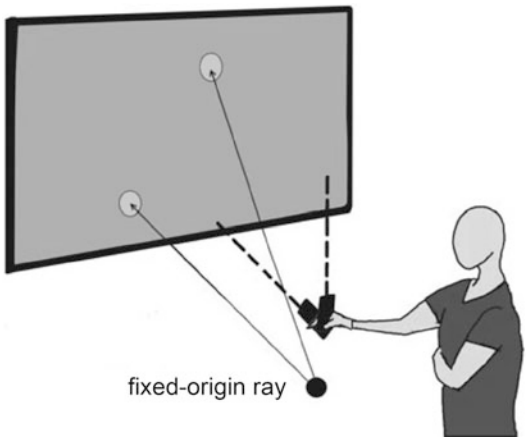
One of the earliest examples of raycasting techniques was called "laser gun" and was introduced by (Liang and Green 1994). Since then, many raycasting techniques were developed for a variety of input devices (Argelaguet and Andujar 2013). A number of specialized raycasting techniques were also developed to address challenges of 3D interaction, such as accuracy and speed trade-off, occlusion, or target density. Common modifications of the technique include adjusting the shape and the size of the selection tool or the shape and the number of rays. Some techniques combine a ray with a 3D point cursor that is contained along the ray.

Notable examples of raycasting techniques include Depth Ray, Aperture Selection, 3D

Bubble Cursor, and Fixed-Origin Raycasting. In Depth Ray (Grossman and Balakrishnan 2006) from all objects intersected by the ray, the one that is closest to the 3D cursor that moves along the ray is the one that is selected. In aperture selection technique (Forsberg et al. 1996), user can manually adjust the selectable areas apex angle. In 3D Bubble Cursor (Vanacken et al. 2007), the size of the spherical cursor at the ray's end expands or shrinks automatically to reach the object closest to its center. In Fixed-Origin Raycasting, the ray originates from a fixed point, rather than the user's hand or input device (Jota et al. 2010; Pietroszek et al. 2014). A comprehensive survey of raycasting techniques was recently published by (Argelaguet and Andujar 2013).

Input Devices

Typically, raycasting requires an input device providing six degrees of freedom (DoFs) – rotation and translation along all thee axis – in order to provide user with full control over the position of the ray origin and the rotation of the ray. High-precision handheld input devices used to implement raycasting include air mouse, magnetic tracker, Oculus Touch tracker, HTC Vive Controller, and PlayStation Move controller. For casual, equitable 3D interaction, techniques utilizing a smartphone or a Wiimote were developed (Pietroszek et al. 2014, 2015). Raycasting can also be realized as a freehand interaction using optical hand tracking, ranging from high-precision motion capture systems, such as VICON or PhaseSpace, to low-cost systems such as Leap Motion and Microsoft Kinect. Alternatively, wearable input devices may be used, including motion capture suits (e.g., Perception Neuron suit), off-the-shelf smartwatch (Pietroszek et al. 2017; Kharlamov et al. 2016), electromyographic sensor (Thalmic Myo), or digital gloves (Senso glove). When the input device does not provide six DoFs, fixed-origin raycasting techniques can be used as an alternative (Jota et al. 2010; Pietroszek et al. 2014), as it requires only three DoFs (Fig. 1).



Raycasting in Virtual Reality, Fig. 1 Smartcasting (Pietroszek et al. 2014): an example raycasting technique using off-the-shelf smartphone as an input device

Conclusion

Raycasting is a family of popular interaction techniques for acquisition of objects presented in virtual reality systems or on large screens. Raycasting techniques offer good accuracy and speed trade-off for 3D target acquisition and a variety of approaches to solve 3D interaction challenges, such as occlusion, fatigue, or high density of objects. For object selection at a distance, Raycasting is de facto a standard 3D selection technique in immersive environments.

Cross-References

- Virtual Hand Metaphor in Virtual Reality
- Virtual Pointing Metaphor

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Reactive Visuals

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Recursive Ray Tracing

► Ray Tracing in Video Games

Redesigning Games for New Interfaces and Platforms

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Synonyms

Adaptation; Crossplatform; Porting

Definition

Redesigning games for crossplatform adaptations and new interfaces (crossplatform game redesign) is to redesign the interface, interaction, user experience (UX), game mechanics, rules, assets, and even the narrative and genre of a game which already existed in its native platform, to fit in the needs, abilities, potentials, and predictions of the new (ported or migrated) platform.

Crossplatform game redesign is a broader range of spectrum than game adaptation, between the two extreme points of the original game itself (a game which was designed in its native platform) and a completely different game (a game which is designed in another platform with a different narration, gameplay, rules, assets, UX, and interface).

Introduction

In the competitive bussiness world of digital games industry, there are many gaming platforms, and these are not identical. There are various gaming platforms developed with several technologies at different decades by different manufacturers. Some dedicated gaming platforms are very small in size to be portable and some are large and powerful machines to drive large screens with high-resolution images. These powerful ones may also be supported with complicated peripheral devices to scan and capture gamers body posture and hand gestures as an input for the gaming interface. Personal computers, mobile devices like mobile phones, tablets, and phablets are also some of the most popular and highly penetrated gaming platforms owned by the most gamers although they are not dedicated platforms for gaming. Virtual reality (VR), augmented reality (AR), and mixed reality (MR or XR) systems also exist with their special headsets.

Light weight handheld paltforms have to overcome the problems of prize, weigt of hardware, battery consumption, and heat while offering optimized quality graphics, enough CPU/GPU power to run games, ergonomics (geometry of the console) to comfortably fit in the hand of the player,

easy to reach buttons, and sometimes feedback systems with sound and vibration. Personal computers are mostly equipped with a mouse pointer, a keyboard, and a flat screen. Mobile devices use touch screen controls which offer a very different interface system with taps and swipes and VR, AR, and MR devices offer interface systems with hand gestures, walking platforms, pods, etc. with the result of an altered user experience.

Game producers develop games for several different platforms. When a game achieves succesful sales figures on a platform (example: on personal computers), producers can decide to port this game to another platform (example: mobile platform) to gain more sales. At this point, depending on the needs of the game, sometimes, game's interface can present difficulties to fit in the target platform and although the new hardware can run the game smoothly, players can complain about the playability of the game. In some cases due to the inconsistencies between the game mechanics and interface, some games can become nonplayable. This can force game designers to redesign the game from scratch or even design a completely new game inspired from the original. The act of redesigning needs further detail and explanation.

The rest of this article is organized as follows: first, background information about basic definitions related with adaptation, remediation, and interfaces will be presented; second, the reasons why crossplatform porting and redesign processes are needed in digital games will be explained; third, dynamics and levels of redesign processes will be presented in detail; and finally, some case studies to illustrate the theories in previous chapters will be presented.

Background Information

Video games are designed to be played on specific hardware platforms. Definition of the word "platform" is mostly based on the context and domain. In transmedia context (transmedia storyteling: Using different media platforms to tell the different parts of one giant story across time. Audience is actively involved and contributes to the narrative by adding content), a platform is "something that supports the channel & media such as YouTube, Soundcloud, Flickr, a shopping mall, a cinema, a web site and so on" (Pratten 2011). In video games domain, a game platform is an environment including software and hardware components which is designed specially for running video games, shortly a console. Platforms naturally define and exist with their specific hardware and interfaces to interact with human beings.

A game console is a special hardware developed to run video games. It includes hardware and software components (a special operating system) with their own technical specifications and limitations. A game console mostly runs games only designed and developed for the specific platform. Specifications and limitations of the hardware also defines the interface and how human computer interaction (HCI) occurs. Consequently, HCI and interface will determine the UX.

In general, interface is the shared boundary between two or more media. In video game context, interface includes hardware, software, and graphical componets which are used for interaction, input, and output. Particularly these are (1) the graphical user interfaces which are seen on the screen, (2)touch screen surface of the device, (3) a mouse pointer, (4) keyboard, (5) game pads with several designs, (6) buttons located on the handheld console, (7) clickers – to use with MS Hololens, (8) VR, AR, MR headsets, (9) cameras, and (6) microphones which can scan the movements and record voice of the gamer as an input source which can be used to interact with the game. Interactivity is a kind of communication in which a message is related with a number of previous messages and relationships between them (Liu and Shrum 2002). In video game context, an example of interaction is controlling a game character by pressing the keys on the keyboard or on a gamepad (interface). Every key is mapped to a special animation of the game character; when a player presses a specific key, it triggers the mapped animation. Results of this interaction is processed by the game system and transferred to the screen (another form of interface) so that the player can decide the next move.

Therefore, in video game context, interface acts as a translator between human and game system. It conveys human behavior, language, gestures to data that can be understood and processed by the computer. In return, the computer conveys and translates results of the processed data coming from game system to information which can be understood and processed by the player.

Essentially, an interface cannot translate transferred information identically between media. Rather, it transforms or interprets gamers' actions and choices to a form in which the game system can understand and process. The degree of exactness, level of similarity, or distance of the interpreted message to the original message can be named as fidelity. As an example, a player mostly interacts with a first person shooter game (FPS) which is running on a personal computer by using WASD keys on the keyboard and keys and movements of the mouse pointer. In this case, the camera in the game world is transformed into the identity of the player's eyes. Player sees the game world with the camera located in the game world. Game camera is also the transformed personality of the game player. Movement of the camera in game world is the movement of the player. By pressing the WASD keys on the keyboard, the player moves or walks in the game world. This is not a translation, instead this is a transformation or interpretation of the reald world action to the game world action with some level of fidelity. Player is not actually walking in the real world to interact with the game, instead she presses the keys and assumes she is walking. Consequently, the game system interprets the keystrokes as the movement of the game camera and game character as they are mapped to predefined actions decided by the game designer.

The technology used by the game interface affects the level of interpretation or transformation, in other words fidelity. In general, technology is systematized practical knowledge that improves productivity (Seels and Richey 1994). In computation context, this term is mostly used as the objectified state of the knowledge or the hardware and software components and the architecture of the system. Therefore, in video game context, an interface technology is the objectified state of the knowledge to design and develop the interface between the player and game system.

Ergonomics is a cross-disciplinary field and, generally, it is the study of the relationship between people and their environment, especially the equipment they use. As it is a cross-disciplinary field, other disciplines such as psychology, engineering, biomechanics, industrial design, physiology, and anthropometry have contributed to the field. Shortly, the act of designing equipments, devices, and processes that can fit the human body dimensions and its cognitive abilities is in the domain of ergonomics. In video games domain, ergonomics can be defined as the study of the relationship between the player and interface, game mechanics, game console geometry, and environment in which the gaming system is located at.

Crossplatform Adaptation of Video Games

Occasionally, preexisting narratives are remediated to different video game platforms (Remediation: The representation or migration of a narrative that was originally created for one type of media to another new type of media or by incorporation of existing and the new media). This phenomenon is called adaptation. According to Flanagan's (2017) definition, adaptation is the movement of textual material from one medium, platform, delivery method, time, or cultural context to another.

This is similar for video games. Video games can be adapted or migrated from one platform to another. This can also be called as crossplatform adaptation. In computing domain, a crossplatform software is a computer program, game, or other content that can run on multiple hardware platforms. Flanagan (2017) encounters four types of adaptation related with digital games: (1) adapting virtual worlds described in original narrative to a digital game world by creating or visualizing the universe as digital and interactive game environment; (2) porting of an existing digital game from one gaming platform (console) to a new gaming platform considering the fidelity of design of

game, assets, mechanics, rules, and UX while optimizing for the hardware needs of the new platform; (3) localization, translation, and cultural specificity while adapting the digital game from one culture to another culture; and finally (4) modding, which is "... the player centric adaptation of game assets, usually through level editing tools released with specific games" (Flanagan 2017). While modding a game, players use level editing tools, existing assets, and game engines to design and develop their own game maps or levels, they can even create new games with new narrative by extending the abilities of the supplied game code, assets, and engine.

Why Crossplatform Redesign Is Needed

Frequently, video games are designed to run on specific platforms, and this choice, which was made by the design and production team in the very beginning of game design process, sometimes alters the narrative, predicts human – game interaction, ergonomy, usability, UX, and also game mechanics. When an existing game is ported from native platform to another hardware platform, the game has to fit and run in the new platform with a different interaction system and hardware specifications, and the change of interaction system will create a different UX. If the aim is running the game on a very different platform such as crossplatform adaptations between personal computer, console, VR, or mobile devices, whole game experience, interaction mechanics, ergonomy and player comfort will change.

The difference between the original interface and target interface can be named as "distance." If interfaces are similar (like a personal computer running on Windows, MacOS or LINUX operating systems, and equipped with common peripherals like a mouse pointer and a keyboard) than the distance between interface systems are small. If original and target interfaces are very different (like Nintendo Game & Watch and Microsoft Hololens) than the distance is large. Different hardware can cause different UX due to their difference of interfaces with various distances to the experince created by the original video game. At some point, the distance between the ported video game and the original video game becomes too much that the ported video game will not give the same feeling of the original or the ported video game becomes unplayable or it can be very difficult for the player to play the game (Fig. 1).

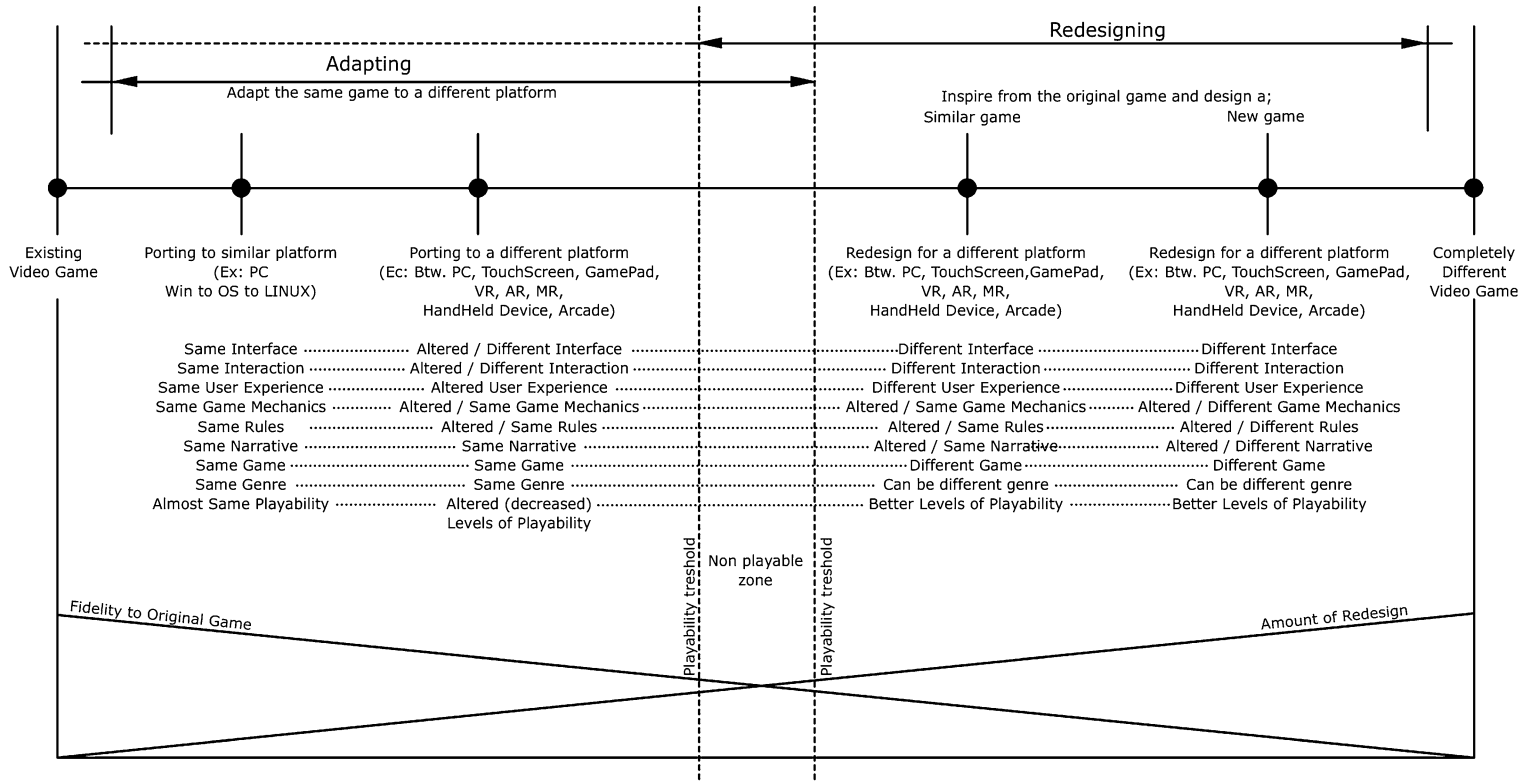
Depends on the platform, player will need some more or less interaction. This can lead to a need of a radical change of the game mechanics and redesigning the gaming experience. At this point, there is an urge to redesign the game mechanics according to the needs of the new platform. Most of the times this can lead to a change to game mechanics and rules or can create an opportunity to design a new game with the inspiration from the original game.

Redesigning in More Detail

Redesigning is the act of designing an existing product partially or completely from scratch due to the changes in factors and needs which made the existing design partially or completely obsolete. In video game domain, some examples to these factors and needs are the differences and developments of interface technologies and new features added to the game systems.

Here, the difference between a remake, clone, and redesign must be emphasized. A remake is adapting the same narrative, same game mechanics, and rules to a very similar or the same platform featuring, mostly, newer technology. A popular example of a remake is Black Mesa (Crowbar Collective 2012): a remake of Half Life (Valve 1998). Original title, Half Life, was released in 1998 for the widely used personal computer technology of the time. Producer continued to extend the story as a sequel with Half Life II (Valve 2004), Lost Coast (Valve 2005), Episode I (Valve 2006) and Episode II (Valve 2007). A sequel is an addition to the original story in forms of a movie, literature, drama, television show, a song, or video game that develops the existing story in the same media channel with the exiting story. Sequels are usually in the same fictional universe with the original work and chronology of narrative follows the original product.

Given: An existing video game (with or without narration)
Target: A new platform (with or without a dedicated device or no device) other than the original platform.
Independent Variables: Interface technology, interaction method, platform.
Dependent Variables: User experience, playability, game mechanics, genre, game rules.


Redesigning
Adapting
Adapt the same game to a different platform
Inspire from the original game and design a;
Similar game
New game
Existing Video Game
Porting to similar platform (Ex: PC Win to OS to LINUX)
Porting to a different platform (Ec: Btw. PC, TouchScreen, GamePad, VR, AR, MR, HandHeld Device, Arcade)
Redesign for a different platform (Ex: Btw. PC, TouchScreen,GamePad, VR, AR, MR, HandHeld Device, Arcade)
Redesign for a different platform (Ex: Btw. PC, TouchScreen, GamePad, VR, AR, MR, HandHeld Device, Arcade)
Completely Different Video Game
Same Interface
Altered / Different Interface
Different Interface
Different Interface
Same Interaction
Altered / Different Interaction
Different Interaction
Different Interaction
Same User Experience
Altered User Experience
Different User Experience
Different User Experience
Same Game Mechanics
Altered / Same Game Mechanics
Altered / Same Game Mechanics
Altered / Different Game Mechanics
Same Rules
Altered / Same Rules
Altered / Same Rules
Altered / Different Rules
Same Narrative
Same Narrative
Altered / Same Narrative
Altered / Different Narrative
Same Game
Same Game
Different Game
Different Game
Same Genre
Same Genre
Can be different genre
Can be different genre
Almost Same Playability
Altered (decreased) Levels of Playability
Better Levels of Playability
Better Levels of Playability
Playability treshold
Non playable zone
Playability treshold
Fidelity to Original Game
Amount of Redesign

Redesigning Games for New Interfaces and Platforms, Fig. 1 General scheme of redesigning games for new interfaces and platforms. (Image created by the author)

For the HalfLife case, the title become so popular that a fan group decided to develop a remake of the first part of the sequel as Black Mesa with new technology and tools supplied by the producer. Narrative and game mechanics were same with the original and, due to the new features of the new technology, game assets were created from scratch with fidelity (but with more detail) to the original. To remind, in game adaptation context, fidelity is the degree of exactness or level of similarity of the ported or the redesigned (hypertext) game to the original or the native game (hypotext).

A clone in video game context is a video game or game console which was heaviliy inspired by or very similar to the original video game. The term usually used with negative meaning for the games whose producers tries to profit off the original games popularity and success and for games that have a lack of creativity or originality.

Finally, redesigning is a spectrum, typically provoked by adapting or especially crossplatform porting, between two extreme points. These are remakes of the same game with very little redesigning, with very high fidelity to the original game, and designing a new game from scratch inspired by and resembling the original at some level. There is always an existing video game with or without a narrative given as a starting point and targeting of a new platform with or without a dedicated device. Independent variables predicted by the target platform, the variables that game designer can not chose, are hardware capabilities, operating system, interface technology, and interaction method. As these are different than the source game, dependent variables are user experience, playability, genre, game mechanics, and rules of the ported game.

Levels of Redesign Processes for Crossplatform Video Games

It is possible to describe five main levels of redesigning. First one is porting the original game to a similar platform. An example of this is porting between Windows, MacOS, and LINUX operating systems running on almost same hardware. Interface and interaction systems are almost the same on these systems, narrative (if any exist), game mechanics, rules, and user experience can work almost the same after porting. This leads to same level of playability on all these systems. Altering controls between keyboard and mouse pointer to game pad can change user experience at some level, but this will not lead to major changes. As popular game engines support all these platforms at the same time, there will be almost no to very little additional programming. Porting from one of these systems to a game console like PlayStation or XBOX also will not lead to radical changes as their hardware and interfaces can support or are compatible with the original game.

Second level is porting a game between uncompatible game hardware. In terms of interaction technologies: PCs typically use keybords, mouse pointers, and game pads; mobile systems use touchscreens; VR, AR, and MR devices interacts with the user through a wide variety of gestures and handheld controller collections; retro handheld consoles use low resolution screens and small buttons scattered around the console; and some game systems can detect body geometry and movement for interaction among other interaction techniques. With this variety of interface and hardware technology and interaction methods, it is not possible to create an exact translation between every platform. Some game mechanics may not work, some part of narrative may not be expressed, original games genre (e.g., 3D FPS) may not fit in the target equipments hardware (e.g., not supporting 3D). In some cases, the hardware can support game engine, but the user interface and interaction methods can be very difficult to adapt.

An example for this is porting a game from a mobile system to a mixed reality system. A mixed reality system can interact with the physical geometry of the surrounding real world environment. This can also add some additional interesting features to a game like letting the player move in the game environment and explore the game in 3D. However, the same system can not support a game pad with buttons and a touchscreen. Technically, a game which was designed to run with a

touchscreen interaction can run on a MR system, but the player cannot interact with the game so game mechanics and experience will either not work or will be very different. Therefore, game designers may need to return to the design stage and start redesigning the game to fit in the target platforms' need and features.

Third level is the extreme zone of the second level where the ported game is not playable anymore because of the inconsistencies between the original and target games hardware, interface, ergonomics, or graphical needs. In some cases, the game can run on the target hardware but players will not prefer to play the game because of these inconsistencies.

At fourth level, redesigning becomes the only way to make the game playable again. Designers can be inspired from the original game, and they can still try to design a similar game. Narrative can be the same or very similar to the original. To satisfy the needs of interface technology, ergonomics, interaction methods, and other features of the target platform, designers can change the game genre, rules, or game mechanics. Therefore, user experience will be very different from the original game. This is not a translation but a completely different interpretation of the original game.

Last level is where designers can be inspired from the original game and design a different game by using the main or totally different game mechanics and rules. The new game may resemble the original game in some sense but for the player it will be obvious that the two games are more different than similar. At this level, there may be no identifiable relation between the narratives of the hypotext and the hypertext. Resemblance may be at the visual level (e.g., using some simiar visual game assets), game rules, or mechanics of the original game.

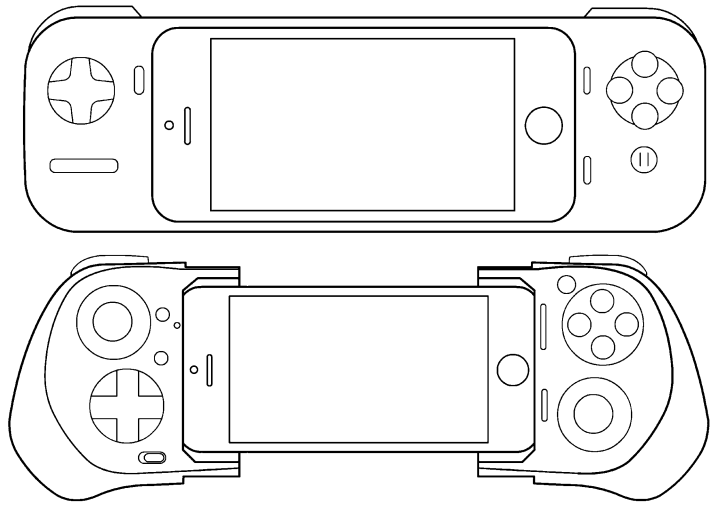
Case Studies

Crossplatform Porting Can Have Negative Effects on Playability

As penetration rate of mobile phones increase in the market, game producers started to port their existing famous titles to several mobile platforms. A mobile platform actually is a pocket-sized general-purpose computer with its special hardware features and limits, interfaces, and own operation systems. App stores contain a lot of general-purpose (word processors, photo scaners, painting software, music players, etc.) software to be installed on a mobile sytem. Games are just some part of these software collection. Most of these systems can also run a software to make telephone calls. So a mobile phone can be counted as a computer more than a telephone. Depending on the size of the hardware, these systems can be called as mobile phones, phablets, or tablets. Mobile systems mostly use touch screens as the interface.

In the mobile platform domain, touch screen controls and swipe gestures can be handy for dialing numbers and making calls. However, for playing games, a touchscreen surface is not an ergonomic choice since it does not provide the physical feeling and feedback of a keystroke or a game pad. This swapping of interfaces can affect the game play experience of the player drastically and even result in a nonplayable game. This can be resulted even with a nonplayable game. Some third party producers developed controllers to mount on the mobile phones to facilitate a gameplay with better ergonomics, feedback, and gaming experience. Logitech PowerShell (Narcisse 2013) and MOGA Ace Power (Fahey 2013) are some of these add-ons (Fig. 2). Some manufacturers even produced bluetooth gamepads to work with mobile platforms. However, these game pads can have compatibility issues with some hardware and games. This can make the game nonplayable.

One of the games whose playability was drastically affected due to the crossplatform porting is Grand Theft Auto III San Andreas (Rockstar Games 2004). GTA is an action adventure, open world, free roaming game in which the player can either follow the scenario and narrative by completing the assigned tasks sequentally, or can complete optional tasks, or experience the city simulation just by walking or driving around the streets of the virtual cities. San Andreas was ported to IOS in 2013. While the PC and console



Redesigning Games for New Interfaces and Platforms, Fig. 2 Examples of add-on game controllers for some smart phones. (Image created by the author)

versions of the game use keyboard controls or game pads, the mobile port was originally designed to interact with the touchscreen. Touchscreen controls are not precise and smooth enough like keyboard controls because of the ergonomic issues between the human hand and the screen. As a result, players complained that it is very difficult or near impossible to complete some of the tasks (Johnson 2013).

The New Platform Can Create Serious Ergonomic Issues

Virtual Reality systems are not new inventions, but as the hardware systems developed to enable more precise and faster detection of an object's position, acceleration and rotation in space, more immersive experiences became possible with cheaper and light-weight systems. Depending on the features of the VR system, a player can experience an immersive world while sitting on a chair or walking freely in a limited part of the real world within the ranges of the sensors. Player can interact with the game through the body movements, gestures, and by pressing the buttons or trigers on the handheld devices. These kinds of interaction modes promise a more immersive experience to the game player, which is closer to the feeling of the real world.

The game world is still not the real world, and VR systems still cannot match with the human balance system. Human balance system is a combination of vestibular organs, eyes, skeletal muscles, and joints equipped with sensory receptors. All these send information to human brain about the current position and balance of the body. If some part of this information is missing, incomplete or inconsistent with the other sensory information, issues like nausea and dizziness can occur, which can make the game nonplayable although it can run on the computer system smoothly.

An example of this is The Elder Scrolls V: Skyrim VR (Bethesda Studios 2017). Several players and game critics mentioned that the VR experience created with this game and several other VR games ported from their original native platforms, mostly PC and game consoles creates strange feelings, nausea, and dizziness. In these examples, VR does not add more playability to the game but instead converts it to some kind of an "elaborate armchair tourism" (Alexandra 2017; Fussel 2017). Fussel (2017) also directly criticizes that playing a VR game while sitting on the chair adds nothing to the game play that was originally designed to play while sitting on a chair but looking at a flat monitor instead of a 360-degrees surrounded environment.

Redesigning the Game for Crossplatform Porting

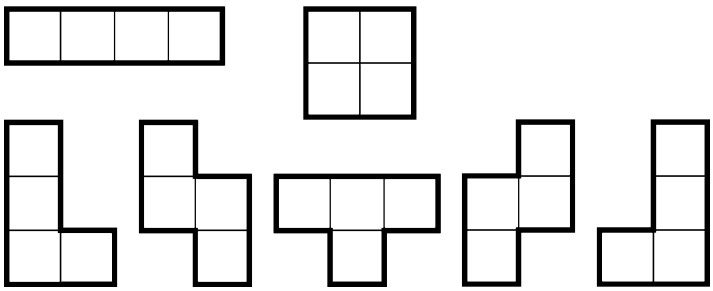
Tetris is one of the most frequently cloned, remade, and ported digital games of all times. Almost every digital game console has a variation

of Tetris. The original game was designed and developed by Russian game designer Alexey Pajitnov, Dmitry Pavlovsky, and Vadim Gerasimov on an Electronika 60 computer and released in 1984 (Gerasimov 2018). Tetris is a tile matching puzzle video game. The whole game contains seven types of puzzle pieces (called as Tetriminos meaning "Tetris Bricks" – Gerasimov uses the word "tetramino" instead in his website.) and all pieces are made by combining four equal sized square units (called tetrominoes meaning a geometric shape composed of four squares) (Fig. 3). The name "tetris" is also derived from the Greek word tetra meaning four. Electronika 60 had no support for graphic elements so tetriminos were created by using alphanumeric characters on a green/black screen (Gerasimov 2018).

Tetris was inspired from a puzzle board game called "pentaminoes." Differently shaped 12 (not counting mirror shapes) puzzle pieces were created by the combining five (penta) equal squares and the aim of the game was to cover an 8×8 (or more) square units board by using pentaminoes without leaving empty squares.

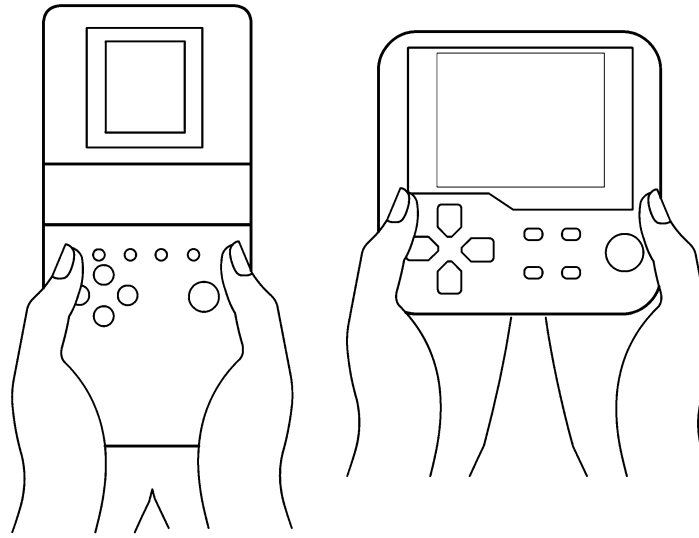
The game objective of tetris is to manipulate the sequentially falling tetriminos by rotating or moving to left and right sides of the game field (matrix) by using keyboard to fill the bottom squares of the matrix without any gaps. Every filled line of squares is deleted from the game field and stacked lines fall down to fill the empty lines.

Tetris was ported to personal computers very quickly by Gerasimov (Gerasimov 2018, Fig. 4). The versions in Electronika 60 and PC's had almost the same interface, and a keyboard to play. Although the graphic assets are more detailed and appealing and the designers added more features to he game for PC versions, the game experience is almost the same for PC ports of Tetris. Original versions use arrow keys and index, middle and ring fingers for controlling tetriminos favouring the right handed players.



Redesigning Games for New Interfaces and Platforms, Fig. 3 Tetriminos. (Image created by the author)

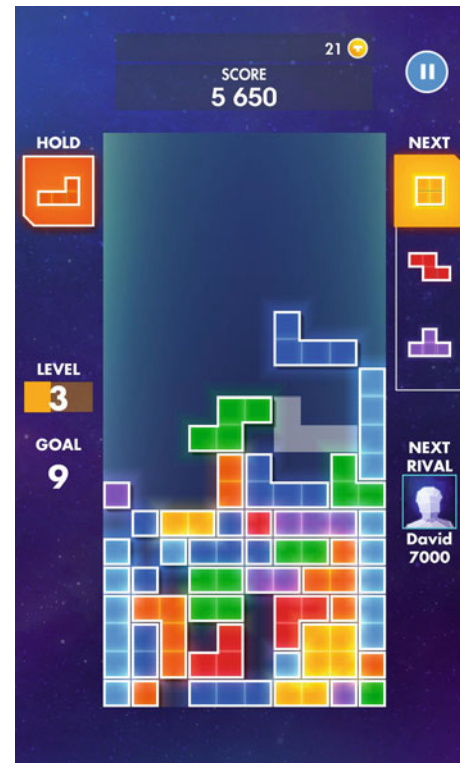
Redesigning Games for New Interfaces and Platforms, Fig. 4 Tetris running on an DVK-2 computer, succesor of Elektronika 60 (Frolov 2009). (Image courtesy of Sergei Frolov)



Redesigning Games for New Interfaces and Platforms, Fig. 5 Several dedicated handheld consoles which runs Tetris clones. (Image created by the author)

Tetris became very popular and the game's penetration rate was so high that special tetris consoles (with different names and slightly different shaped tetriminos) were produced. Because of the geometry and size of these consoles, users must hold these machines with two hands while using left hand thumb finger to move and right hand thumb finger to rotate pieces – a design which creates slightly different game experience and control precision (Fig. 5).

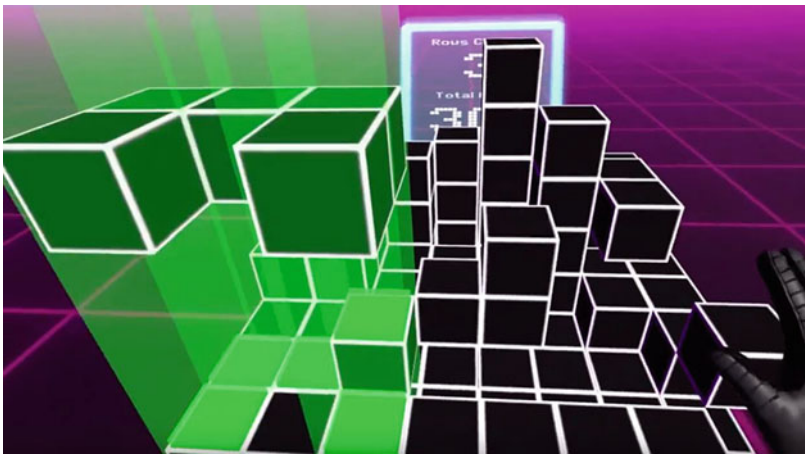
After more than 20 years of its first release, when smart phones become popular in first decade of 2000s, several tetris ports which can run on smart phones were introduced to the market. Since the common types of smart phones use touch screens, taps, and swipe gestures, most ports of tetris to mobile platforms also use taps on touchscreen to mimic buttons of the keyboard. Tapping on the screen has a very different feeling and a lack of feedback compared to pressing a real button. This, typically, changes the gaming experience negatively. So some ports of tetris for smart phones were dramatically redesigned while keeping the simple game mechanics while adding a lot more gaming and controlling features (e.g., refining swipes to move pieces with tapping at any place on screen instead of a virtual button) consistent with the dynamics of screen wipes and tapping (TouchArcade 2008; Electronic Arts 2011; Cassidy 2017). These were some examples to cover the subject adapting the same game to different platforms (Fig. 6).



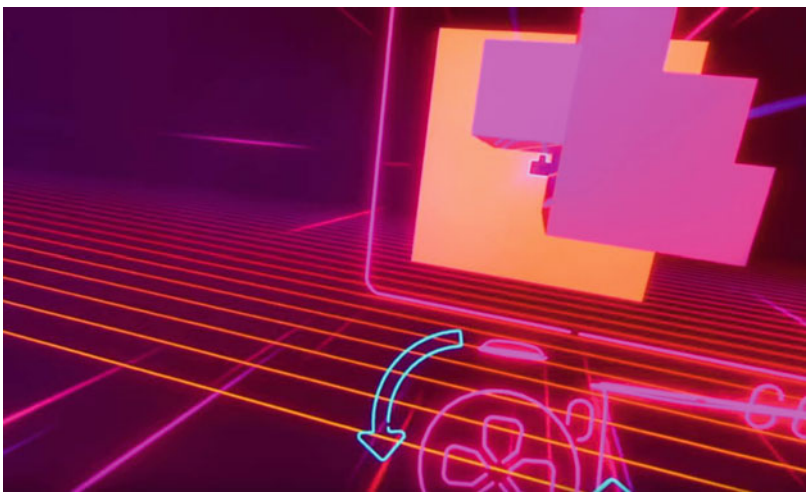
Redesigning Games for New Interfaces and Platforms, Fig. 6 Electronic Arts Tetris version for mobile platform. (Image captured by the author)

There are also other examples of redesigning a tetris like game while being inspired by the original game. The original tetris is a two-dimensional game, and it mimics the falling pieces viewed from the side-view by the player. When it is time to port this two-dimensional game to an immersive environment, two-dimensional nature of tetris is not enough for the features and potential of the VR environment. On one hand, creating a tetris game using three-dimensional pieces with same game mechanics and rules can techically run on a VR hardware. However, on the other hand, VR environment is a 360-° environment and by using special sensors, players can walk around and observe any three-dimensional object from all angles. Compared with the keyboard keys, handheld triggers and button sets are not very precise and ergonomic for the precision needs of tetris. That's why, in this case simply porting the same game to VR environment is almost nonplayable.

BlockWave (RLTYCHK 2016) and Super Hyper Cube (Kokoromi 2016) are two examples of redesigned games influenced by from tetris. Compared to Super Hyper Cube (Fig. 8), BlockWave (Fig. 7) is a game more similar to the original tetris, and it looks like the two-dimensional game area was replaced with a three-dimensional volumetric game space. Supporting this decision, tetrinos are created as three-dimensional pieces and moving and rotation of pieces are made possible by touching the virtual



Redesigning Games for New Interfaces and Platforms, Fig. 7 A screen shot during game play from Block Wave VR (2016). (Image captured by the author)



Redesigning Games for New Interfaces and Platforms, Fig. 8 A screen shot during game play from Super Hyper Cube (2016). (Image captured by the author)

objects through hand controllers. Super Hyper Cube on the other hand uses pieces looking like tetrinos, but they have more variations and can change geometry in time. Some game mechanics were also borrowed from tetris (e.g., placing the correct piece geometry into a gap in an incoming obstacle coming through the camera to destroy the obstacle and make camera continue to move forward).

Conclusion

Here it was defined five levels in game redesign processes of games in three main zones that were ported to another platform. Shortly, first group was adapting the same game to another platform. This group has two levels in relation with the fidelity of the ported game to the original game by means of game elements and interfaces. These were porting to a similar platform and porting to a different platform. Porting a game to a similar platform usually has no critical effect on game dynamics and experience. Porting to a different platform, due to the inconsistencies in interface technologies of the original and the new platforms, can have some serious effects on game dynamics and can force designers to redesign main game elements to keep the game playable. Second zone, third level, is nonplayable zone. A game falls in this zone when the inconsistencies between the interfaces of the original and the new platforms are so serious so that even though the game can run on the new platform technically, players can not play or not prefer to play the game. Last zone is the redesign zone consists of two levels. These are: inspire from the original game and design a similar game, or inspire from the original game and design a new game. A similar game is not the same game running on the new platform, but still resembles the original game with serious changes in main game elements to meet the needs and features of the new platform. At this level, changes in narrative and genre can be seen frequently in the ported game. Last level is designing a new game inspired by the original game. At this level, the new game hardly resembles the original game but traces of the original game can be still recognizable by the player.

In the future, new game consoles and technologies will be developed. Any new computing technology will exist with its unique interface technology. Games will also be adapted and ported in crossplatforms in the future. As long as the distance between the original interface and new interface is large enough to be located beyond the nonplayable zone, game designers will create redesigns to make their games playable. Redesigning can be a good way to keep games up-to-date and even create new games inspired by the original game.

Cross-References

- ▶ Decoupling Game Tool GUIs from Core Editing Operations
- ▶ Game Writer's Dilemma: Context vs. Story
- ▶ Narrative Design
- ▶ Narrative in Video Games
- ▶ User-Centered Design and Evaluation Methodology for Virtual Environments

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Redirected Walking

► Spatial Perception in Virtual Environments

Redirected Walking in Virtual Reality

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Synonyms

Redirection techniques

Definitions

Redirected Walking (RDW) is a collection of virtual reality (VR) locomotion techniques for immersive virtual environments (IVE) that enables humans to walk on paths in the real world, which may vary from the paths they perceive in the virtual environment (VE). RDW can be implemented by manipulations applied to the displayed scene, usually by using redirection gains, which force the user to compensate by repositioning and/or reorienting themselves in order to maintain their intended walking direction in the VE. Within certain detection thresholds, such manipulations cannot be noticed by the user.

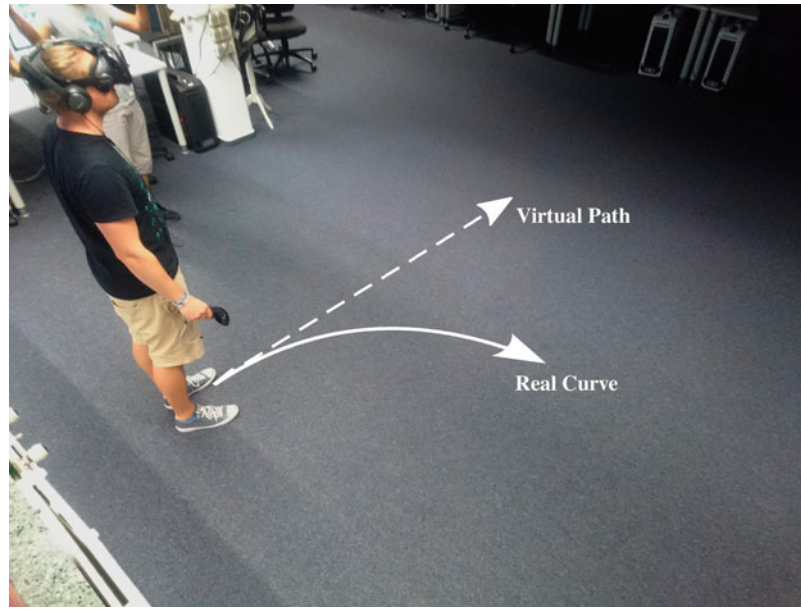
Introduction

Locomotion is one of the most important forms of interaction in VR, but its realistic implementation is also one of the most challenging task in VR development (Steinicke et al. 2013). Real human walking is the most natural way of locomotion in VR (Steinicke et al. 2013) due to its multimodal nature. Furthermore, real walking is beneficial regarding the increased sense of feeling presence (Usoh et al. 1999), improved spatial knowledge (Peck et al. 2011; Ruddle and Lessels 2009; Ruddle et al. 2010), or reduced VR sickness symptoms (LaViola Jr 2000). When using real walking, unfortunately the size of the VE is limited to the size of the tracking space in the physical world. Therefore, a lot of alternative locomotion techniques have been developed, for example, virtual travel techniques such as teleportation (Bozgeyikli et al. 2016) or flying (Usoh et al. 1999), hardware devices like omnidirectional treadmills or motion platforms (Bouguila and Sato 2002; Iwata et al. 2006; Schwaiger et al. 2007), and walking-in-place (Langbehn et al. 2015; Nilsson et al. 2016a). An interesting collection of techniques are Redirection Techniques because they promise to combine the advantages of real walking with the exploration of unlimited VEs. This entry provides an overview of different redirection techniques, including steering algorithms, resetting techniques, and detection thresholds.

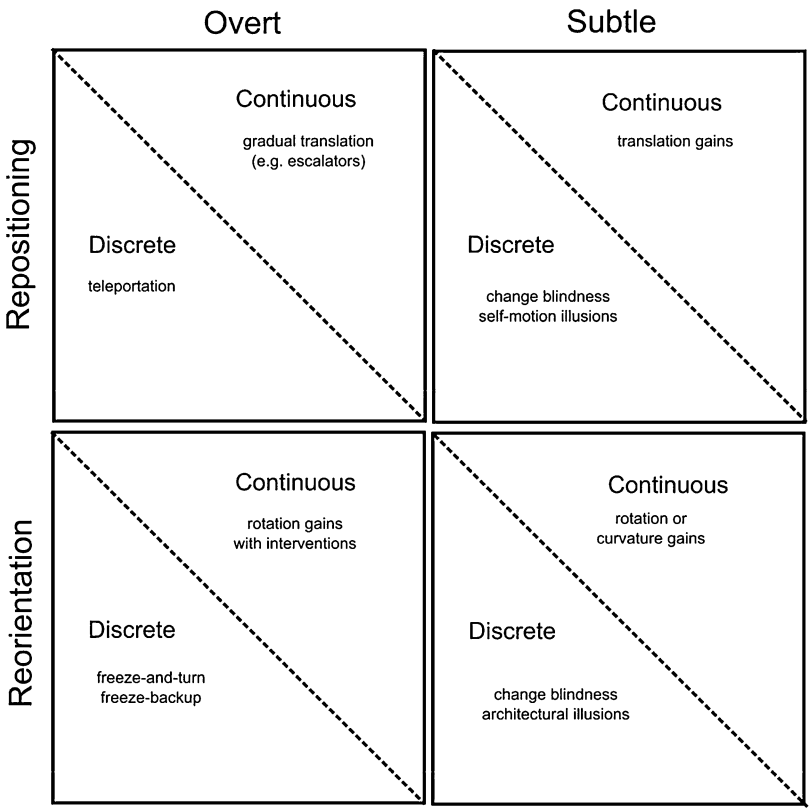
Redirection Techniques

The traditional approach of Redirected Walking that was introduced by Razzaque et al. (2001) is based on slightly rotating the user's view to one direction while she walks on a straight path in the VE. Then, she will unconsciously compensate the rotation by walking on a curved path in the opposite direction. As a result, she will walk on a circular arc in the real world (cf. Fig. 1). About a decade later, Steinicke et al. revisited this technique and described this and other manipulations by means of gains. For example, curvature gains can be defined as follows: $g_C := \frac{1}{r_{real}}$ where r_{real} describes the radius of the circle on which the users are guided in the real world (Steinicke et al. 2010). When redirecting a user, her visual feedback is consistent with movements in the VE, but proprioceptive and vestibular feedback systems are coupled to the physical world. It is known from perceptual and cognitive psychology that vision often dominates proprioception and vestibular sensation when the information from these senses is in conflict (Berthoz 2000; Dichgans and Brandt 1978). However, if the visual-proprioceptive conflicts are small enough, humans will not even be able to notice that they are manipulated. In perceptual experiments where human participants can use only vision to judge their motion through a virtual scene, they can successfully estimate their momentary direction of locomotion, but are worse in perceiving their paths of travel (Bertin et al. 2000; Lappe et al. 1999). Since humans tend to compensate for slight visual-proprioceptive inconsistencies during locomotor control while walking, it becomes possible to guide users along real-world paths, which differ from the paths they perceive in the virtual world.

There are several other redirection techniques in addition to curvature gains. While the traditional RDW approach is based on curvature gains, the terms Redirected Walking and Redirection Techniques are often used almost interchangeably. Suma et al. introduced a taxonomy of Redirection Techniques (cf. Fig. 2) that classifies these techniques into the categories Repositioning or Reorientation, Subtle or Overt, and Discrete or Continuous (Suma et al. 2012a). Repositioning techniques manipulate the position of the virtual viewpoint of the user, whereas reorientation techniques manipulate their orientation, which are usually focused on the yaw rotation. Subtle techniques are intended to be not noticed by the user, that is, manipulations are below the user's detection thresholds.



Redirected Walking in Virtual Reality, Fig. 1 A user walking virtually straight while being redirected using a curvature gain



Redirected Walking in Virtual Reality, Fig. 2 Taxonomy of redirection techniques. (Adapted from Suma et al. 2012a)

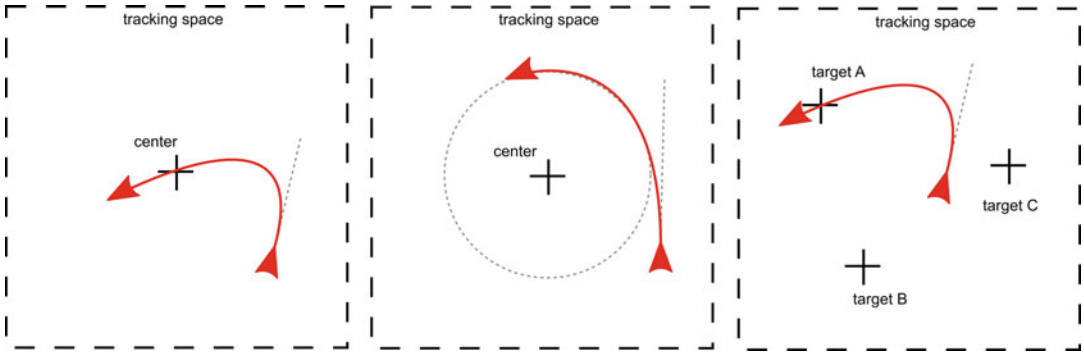
Discrete techniques redirect the user in discrete steps. For example, instant teleportation (Bozgeyikli et al. 2016) is a discrete overt repositioning technique, and impossible spaces (Suma et al. 2012b) are a discrete subtle redirection technique based on scene layouts, which would be impossible in the real world. For instance, such impossible spaces are composed of scenes whose architecture is self-overlapping or changing when the user does not pay attention. Continuous techniques, on the other hand, make use of a continuous motion. One set of techniques in this category are gains for translation, rotation, and also curvature. A gain describes differences between real and virtual motions, that is, ratios between a user's movements in the real world and in the VE. A translation gain $g_T = \frac{T_{virtual}}{T_{real}}$ manipulates the virtual velocity of the user, making her walk slower or faster in the VE compared to the velocity in the real world (Interrante et al. 2007). A rotation gain $g_R := \frac{R_{virtual}}{R_{real}}$ increases or decreases the virtual rotation of the viewpoint relative to the rotation in the real world.

However, no matter which technique is used, when the user hits a boundary of the tracking space, she has to be stopped and reset in a suitable way. For this resetting phase, several discrete and continuous approaches exist, for example, freeze-and-turn (Williams et al. 2007) or visual distractors (Peck et al. 2008).

Steering Algorithms

When implementing RDW with curvature gains, two things have to be provided or assumed: (i) the target of the user in the VE and (ii) the target of the redirection in the real world. Then, the amount of redirection, that is, the gain, can be calculated and a corresponding rotation can be applied to the user's view.

The target of the user can be predicted by using the current gaze direction, which is available



Redirected Walking in Virtual Reality, Fig. 3 Steering algorithms: Steer-to-center, steer-to-orbit, and steer-to-multiple-targets. (Adapted from Razzaque 2005)

through rotational head tracking (Steinicke et al. 2008c) or eye tracking (Zank and Kunz 2016), the past walking direction (Zank and Kunz 2015), or the direction of the user's torso. A combination of these methods or the usage of probabilistic models is also possible (Schrempf et al. 2007).

In small tracking spaces, it is required to steer the user away from the boundaries. Therefore, Razzaque proposed three algorithms: (i) steer-to-center, (ii) steer-to-orbit, and (iii) steer-to-multiple-targets (Razzaque 2005). These techniques are based on the idea to redirect the user always to a certain point, on a certain orbit, or to multiple certain points (cf. Fig. 3), that is, these are the targets of the redirection in the real world. In these scenarios, the user's walking direction is constantly changing while she is walking freely in the virtual world. Hence, the required amount of redirection is constantly recalculated so that the user is always steered towards these certain points or orbits. Hodgson et al. (Hodgson and Bachmann 2013) added the (iv) steer-to-multiple-centers algorithm, which is an extension of the steer-to-multiple-targets algorithm, and compared them regarding metrics like number of wall contacts and maximum distances from the tracking area center. In these experiments, steer-to-center showed the best performance. In another experiment, where the VE was constrained by virtual walls and the walking directions were therefore limited, steer-to-orbit performed better (Hodgson et al. 2014). In general, larger tracking spaces offer improved performance starting with a minimum viable size of approximately 6×6 m (Azmandian et al. 2015). Instead of using the center or random targets, it might be beneficial to use physical proxy objects inside the tracking space as steering targets (Steinicke et al. 2008c). These objects can provide the user with passive haptic feedback for unlimited virtual objects (Kohli et al. 2005). Hodgson et al. (2011) introduced a generalized RDW algorithm for gymnasium-sized spaces while others implemented their algorithms for spaces with a size of approximately 6×6 m (Suma et al. 2015).

In order to guide users always in an optimal way, a planning method can be used to select the most suitable redirection technique for a given situation (Zmuda et al. 2013). Therefore, a manually defined graph of weighted walking paths based on the known VE is used to predict the user's travel path. This technique revealed a significant improvement compared to the steer-to-center algorithm (Nescher et al. 2014). Furthermore, it has been shown that the graphs can be generated automatically based on navigation meshes (Azmandian et al. 2016b; Zank and Kunz 2017). Another method is to map virtual and physical reality in such a way that only a minimal redirection is necessary (Sun et al. 2016; Nitzsche et al. 2004).

There were also approaches, which combined RDW algorithms with other travel techniques such as portals (Bruder et al. 2009; Steinicke et al. 2009; Freitag et al. 2014) or redirection-free zones (Lubos et al. 2014). Recently, a method of RDW

Redirected Walking in Virtual Reality, Fig. 4 Illustration of the RDW approach based on virtual curves: (a) a virtual pathway in the VE constructed of several curves and intersections with (b) the corresponding real-world walking configuration consisting of several curve segments in the laboratory. The presented application requires approximately a tracked real-word space of about 4 m × 4 m, whereas the VE presents approximately a 25 m × 25 m large model

has been introduced, which constraints walking in the VE to curved paths (Langbehn et al. 2017b). For this, several curves are fitted into the tracking space and connected at specific intersections at which the user can change her walking direction. This way the boundaries of the tracking space are never hit as long as the user stays on the predefined paths in the VE (cf. Fig. 4).

Resetting Phase

No matter which redirection technique or steering algorithm is used, it can still hap-pen that the user hits a boundary of the tracking space. In this case, she needs to be stopped and reset, that is, the user must be turned to face to the center of the tracking space again. For instance, most redirection solutions, for example, the RDW toolkit (Az-mandian et al. 2016a), make use of a stop-and-go approach. Using these approaches, the user walks until the boundary of the tracking space is reached, for example, while a curvature gain is applied. Then, she will be rotated until there are no obstacles in front of her new walking direction. Afterwards, the user can continue walking in the desired direction.

For this resetting phase or reorientation phase, several techniques exist. Williams et al. introduced the three methods (i) Freeze-Backup, (ii) Freeze-Turn, and (iii) 2:1-Turn (Williams et al. 2007). In the Freeze-Backup method, the position of the user in the VE is frozen and she can walk backward until she has enough empty physical space in front of her. In the Freeze-Turn method, the orientation of the user in the VE is frozen and she can turn around until she has enough empty physical space in front of her. In the 2:1-Turn method, the user turns around 180 degrees physically (so that she has enough empty physical space in front of her), while she turns 360 degrees virtually (and looks in the same direction in the VE as before the turn). Such a manipulated turn is implemented using a rotation gain $g_R = 2$. In this case, visual distractors can be used to make these manipulated turns less obvious and to appear more natural (Peck et al. 2008, 2011). The resetting phase can also be integrated into the domain of the VR application by using suitable metaphors, for example, a turning bookshelf (Yu et al. 2017).

To reduce the number of resetting phases in this stop-and-go approach, Zhang et al.

Redirected Walking in Virtual Reality, Table 1 Detection Thresholds of Redirection Techniques

Gain	Comment	Thresholds[a]	=°/m Notation[b]	Source
Translation	Question Bias	0.78–1.22	–	(Steinicke et al. 2008a)
Translation	–	0.78–1.22	–	(Steinicke et al. 2010)
Translation	–	0.87–1.29	–	(Bruder et al. 2012)
Translation	Driving	0.94–1.36	–	(Bruder et al. 2012)
Translation	–	0.86–1.26	–	(Kruse et al. 2018)
Translation	Virtual Feet	0.88–1.15	–	(Kruse et al. 2018)
Translation	Low-cue VE	0.73–1.25	–	(Kruse et al. 2018)
Rotation	Question Bias	0.59–1.1	–	(Steinicke et al. 2008a)
Rotation	–	0.67–1.24	–	(Steinicke et al. 2010)
Rotation	–	0.68–1.26	–	(Bruder et al. 2012)
Rotation	Driving	0.77–1.26	–	(Bruder et al. 2012)
Rotation	–	0.93–1.27	–	(Paludan et al. 2016)
Rotation	16 objects	0.82–1.20	–	(Paludan et al. 2016)
Curvature	Question Bias	$r > 16$ m	3.5 = °/m	(Steinicke et al. 2008a)
Curvature	Question Bias	$r > 24$ m	2.35 = °/m	(Steinicke et al. 2008a)
	& 2 m start-up	$r > 22.03$ m	2.6 = °/m	
Curvature	–			(Steinicke et al. 2010)
Curvature	–	$r > 14.92$ m	3.84 = °/m	(Bruder et al. 2012)
Curvature	Driving	$r > 8.97$ m	6.39 = °/m	(Bruder et al. 2012)
Curvature	$v = 0.75$ m/s	$r > 10.57$ m	5.42 = °/m	(Neth et al. 2012)
Curvature	$v = 1.00$ m/s	$r > 23.75$ m	2.41 = °/m	(Neth et al. 2012)
Curvature	$v = 1.25$ m/s	$r > 26.99$ m	2.12 = °/m	(Neth et al. 2012)
Curvature	–	$r > 11.61$ m	4.9 = °/m	(Grechkin et al. 2016)
Curvature	Audio	$r > 27.5$ m	2.08 = °/m	(Serafin et al. 2013)
Curvature	Audio & Vision	$r > 6.0$ m	9.55 = °/m	(Meyer et al. 2016)
Bending	$r_{real} = 1.25$ m	3.25	31.7 = °/m	(Langbehn et al. 2017a)
Bending	$r_{real} = 2.5$ m	4.35	17.6 = °/m	(Langbehn et al. 2017a)

[a]For translation and rotation gains, the range of undetectable gains is stated. For bending gains, the maximal gain is stated. For curvature gains, the radius of the resulting arc in the real world is stated

[b]For comparing curvature and bending gains, this notation is more suitable since it does not rely on the radius of the curves. It can be calculated if real and virtual radii are given

(Zhang and Kuhl 2013; Zhang et al. 2015) developed heuristics to dynamically adjust RDW gains for guiding the user in the best direction. It turned out that the users walked a significantly longer distance between two resetting phases when using this method.

Detection Thresholds

Redirection techniques may be subtle under certain conditions. Therefore, detection thresholds for different manipulations have been analyzed. We collected several estimated detection thresholds for different gains and conditions in Table 1.

Steinicke et al. conducted several experiments to reveal detection thresholds for translation, rotation, and curvature gains (Steinicke et al. 2010). The detection thresholds indicate just-noticeable differences between vision and proprioception. In order to determine these thresholds, a two-alternative forced-choice (2AFC) task was used. This means, for example, for path curvature, users walked a straight path in the VE, which was bent by a curvature gain either to the left or to the right

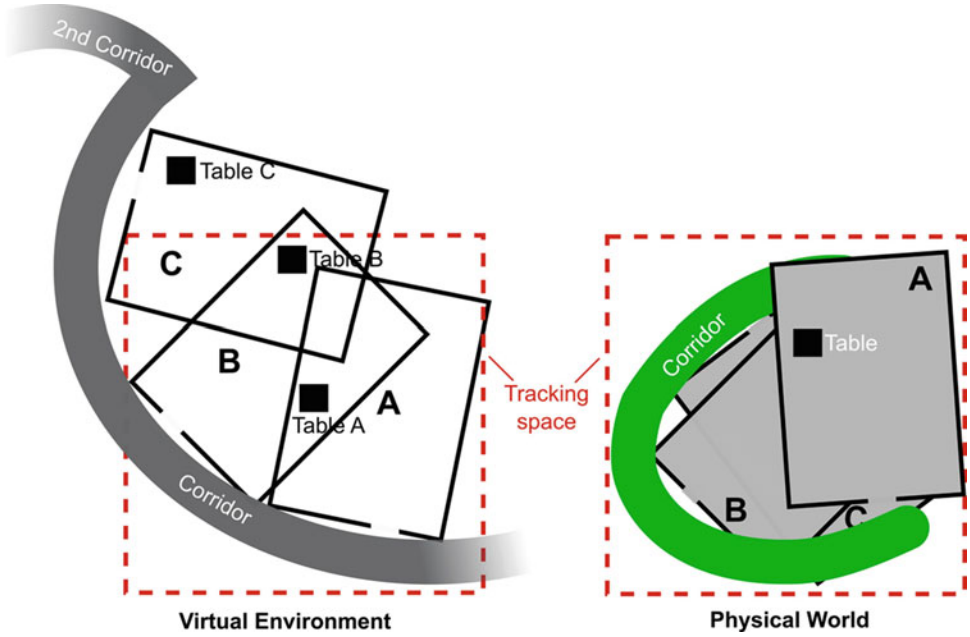
in the real world. Then, they had to judge if the physical path was bent left or right. The pooled data of this task can be used to generate a psychometric function that determines the detection thresholds. While there most likely was a bias in the question of their first experiments (Steinicke et al. 2008a), they repeated them (Steinicke et al. 2010). Accordingly, a straight path in the VE can be turned into a circular arc in the real world with a radius of at least 22 m, for which users are not able to consciously detect manipulations. This means that a physical space of at least 45 × 45 m would be necessary to enable infinite virtually straight walking. Furthermore, rotations can be scaled by gains between 0.67 and 1.24 and translations can be scaled by gains between 0.78 and 1.22 without that users are able to detect the manipulations.

These experiments have been replicated and extended several times (Steinicke et al. 2008b, 2009; Bruder et al. 2012). It was shown that rotation manipulations are less obvious to detect if the VE moves against head rotation than if the VE moves with head rotation (Jerald et al. 2008). It was found that sensitivity to curvature gains depends on walking velocity: a slower walking speed allows higher redirection gains (Neth et al. 2011, 2012). Redirection can also be applied for driving simulations, for example, when applying curvature gains to a user sitting in an electric wheelchair, this resulted in greater possible redirection (Bruder et al. 2012), which might be related to the proprioceptive feedback users receive by walking, whereas this feedback is mostly missing while driving in a wheelchair. When combining curvature gains and translation gains, curvature detection thresholds are not affected (Grechkin et al. 2016). So far, curvature detection thresholds were estimated when the users walk straight ahead in the VE. Recently, the concept of curvature gains has been extended to so-called bending gains $g_B := r_{virtual} \times g_C = \frac{r_{virtual}}{r_{real}}$, which define how much a physical path can be bent for situations in which users do not walk straightforward, but walk on a virtual curve in the VE (Langbehn et al. 2017a). An effect of the visual density of the VE, that is, the number of visual objects that were present in the VE, on the detection thresholds could not be shown (Paludan et al. 2016). However, the visual fidelity of the VE is more important than the visualization of the user's feet (Kruse et al. 2018). Subtle redirection techniques may not only be based on visual manipulations of the VE, but also on audio (Meyer et al. 2016; Nilsson et al. 2016b; Nogalski and Fohl 2016) or haptics (Matsumoto et al. 2016b). When using passive haptic cues during RDW even more redirection is possible (Matsumoto et al. 2016a). Of course, detection thresholds may be individually different for different users (Thi Anh Ngoc et al. 2016).

Although, ideally RDW is a subconscious process, Bruder et al. have shown that cognitive resources are required to compensate even subtle manipulations (Bruder et al. 2015). In secondary verbal and spatial memory tasks, they have shown that performance decreased in the secondary task when the redirection gain increased. More precisely, correct answers decreased and answer time increased as well.

Redirected Spaces

An alternative approach to implement RDW is to use impossible or flexible spaces (Va-sylevska et al. Vasylevska et al. 2013), which can be based on self-overlapping or changing architectural layouts. In these spaces, the VE itself is manipulated (in contrast to the user's viewpoint) with the same goal of enlarging the virtual space, which can be explored by real walking. Such manipulations can be realized, for example, by moving walls or doors outside the user's view (Suma et al. 2010) to exploit the same real-world space for different virtual rooms. The phenomenon that users are unable to detect such changes is known as change blindness (Simons and Levin 1997). It was shown that virtual rooms may overlap by more than 50% before users detect the manipulation (Suma et al. 2012b). Moreover, curved corridors between the overlapping rooms are more beneficial than right-angled corridors in



Redirected Walking in Virtual Reality, Fig. 5 An illustration of the combination of redirected walking and impossible spaces. The virtual environment consists of a curved corridor and rooms A, B, and C. The corridor and the rooms are larger than the available tracking space although the rooms overlap already (left). When applying a redirection gain at the corridor the VE is compressed even more and the whole setup fits into the tracking space (right). There the virtual tables are merged into one physical table. This design can be repeated with another corridor that is connected to the first one

terms of manipulation detection (Vasylevska and Kaufmann 2017), and a corridor with additional turns is more efficient than a longer corridor (Vasylevska and Kaufmann 2015).

Impossible spaces can be combined with curvature-based RDW (Langbehn et al. 2018) to leverage a small tracking space optimally (cf. Fig. 5). In particular, the use of curved corridors benefits both methods (Vasylevska and Kaufmann 2017; Langbehn et al. 2017a).

Conclusion

Although a lot of research results were collected since RDW was first introduced, there is still no standard solution for unlimited walking in a restricted tracking space without interruptions. However, the existing techniques can already be used for different applications, for example, games (Steinicke et al. 2009) or architecture (Bruder et al. 2009). For future work, there are challenges in all areas of RDW. Steering algorithms and path prediction methods might be improved using machine learning algorithms. Procedural generation of virtual worlds might simplify the use of impossible spaces. Furthermore, detection thresholds might be investigated regarding their usability, since even perceivable gains might be acceptable by users. It is also not known if users adapt to redirection and if it might be possible to increase a gain after a certain while in the VE. Moreover, there is little work on RDW in multiuser environments so far (Azmandian et al. 2017).

To summarize, redirected walking is a fascinating field of VR, which combines the fields of human-computer interaction, computer science, and psychology allowing users to explore a VE in the most natural way, that is, by real walking.

Cross-References

- ▶ Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology
- ▶ Locomotion in Virtual Reality Video Games
- ▶ Natural Walking in Virtual Reality
- ▶ Perceptual Illusions and Distortions in Virtual Reality

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Redirection Techniques

▶ Redirected Walking in Virtual Reality

Regional Game Studies

▶ Video Game Culture in Cape Town, South Africa

Regression

▶ Machine Learning for Computer Games

Rehabilitation

▶ Accessibility of Virtual Reality for Persons with Disabilities
▶ Computer Games for People with Disability
▶ Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being
▶ Immersive Virtual Reality Serious Games

Rehabilitation Games

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Synonyms

Exergames

Definitions

Rehabilitation games are a subset of serious games intended to promote increased musculoskeletal or neural activity with the aim of therapeutic benefit in the patients or players of these games. This encyclopedia entry is in a digital context.

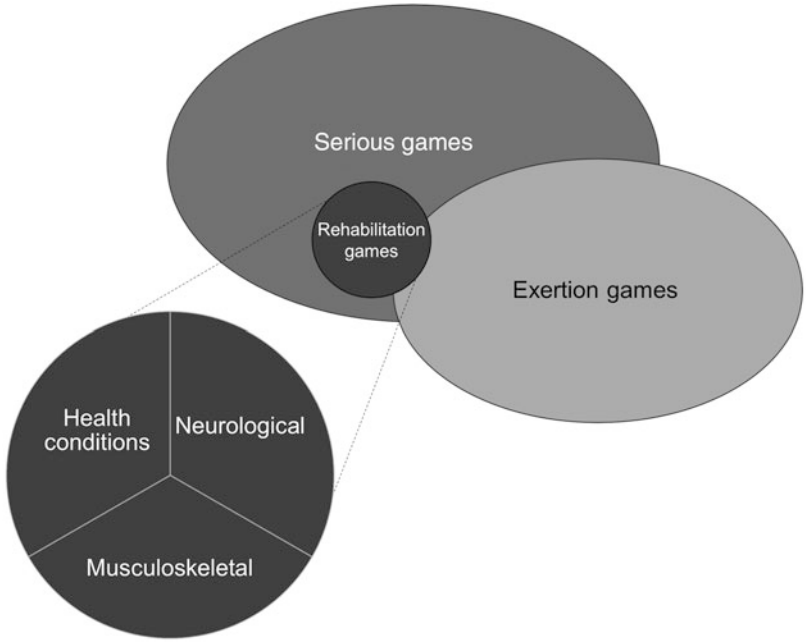
Introduction

Serious games, often called games for learning, are games intentionally created for more than mere entertainment (Abt 1970), and in the advent of digitalization, the term digital games based learning (DGBL) has enjoyed widespread synonymic acceptance. DGBL, as the name suggests, encompasses all digital games that are created with intent to facilitate learning – be it to acquire knowledge, change behavior, or improve motor and neuro functioning. Another such term that gained popularity, largely due to console platforms such as Nintendo Wii and Xbox Kinect (and their respective game releases), is exertion games (exergames). Although exergames are generally directed at physical exertion that goes beyond couch-bound gameplay (Oh and Yang 2010), when the aim of exergaming becomes an attempt at changing habitually sedentary behavior into active behavior, an overlap with serious games emerges.

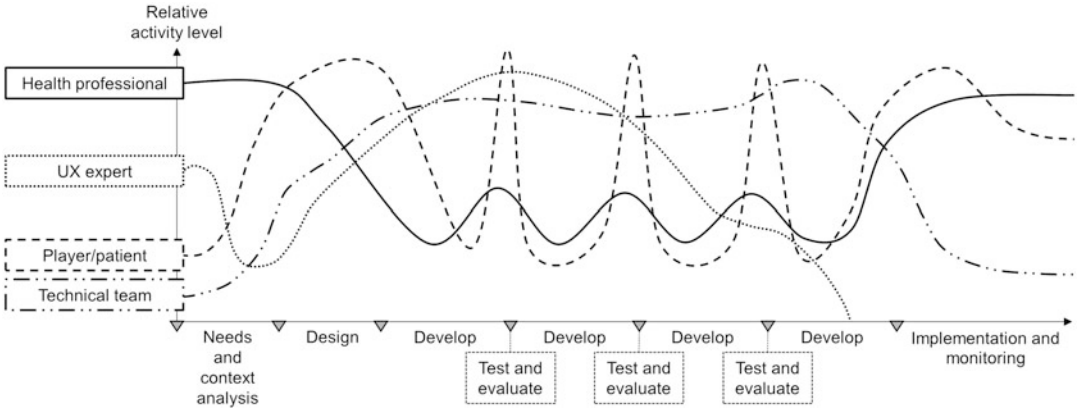
Rehabilitation games, on the other hand, are considerably more directed and have found a niche application as tools for therapeutic recovery or rehabilitation from a host of health related matters (Fig. 1). That is, rehabilitation games are set upon players learning to improve or regain motor and neuro functioning (Rego et al. 2010), positioning such games squarely as a subset of serious games (Fig. 1). Furthermore, rehabilitation games can address, by means of improved cardiovascular fitness, physiological health conditions such as acute hypertension, raised blood sugar, or heightened cholesterol. Since improved cardiovascular fitness falls in the exergaming realm, an intersection between exergames and rehabilitation games becomes apparent (Fig. 1).

Where the success of serious games is continuously challenged with striking an equilibrium between pedagogy and fun, rehabilitation games add control accuracy as a third aspect to this precarious balancing act. It is not enough to merely add an appealing layer of engagement to a set of prescribed exercises. Even if this engagement follows all the guidelines for successful serious games, there exists a real risk that players could injure themselves if their movements are not conducted with strict form (Saini et al. 2012). Additionally, rehabilitation games are typically destined for those who are likely to be (out of fear for re-incurring their injury) reluctant to play, making that the user experience becomes ever more important in overcoming the challenged internal motivation to engage with such games.

Rehabilitation games are primarily in place to encourage a persistent engagement with activities until complete rehabilitation has taken place. In other words, rehabilitation games must motivate. All this makes for a significantly complex kaleidoscope of factors and role players to be considered when designing, developing, and implementing rehabilitation games.



Rehabilitation Games, Fig. 1 Primary application categories of rehabilitation games and positioning of rehabilitation games within the serious and exertion games space



Rehabilitation Games, Fig. 2 Timeline for rehabilitation game development phases that shows the relative activity levels for each of the key role players

The Development Process

Rehabilitation games are born from the human body's biokinetic and neurological ability to recover from various injuries. Rehabilitation games have human users. In extension, users of rehabilitation games should not be regarded as players but rather as patients with personal agendas, motivations, and practical environments. Neglecting to consult the patients of rehabilitation games from early phase conceptualization through to implementation (Fig. 2) is bound to result in poorly construed games that will find a dusty shelf rather than active interaction with the patient. The strong patient presence during the design phase (Fig. 2) reverberates the general notion that a serious game's target audience should be valued as co-designers (Ravyse et al. 2017), rather than users only for testing.

Representing users of rehabilitation games as patients implies that a health professional forms part of the recovery process and hence also the

game development process. These health professionals have a dichotomous role of conveying the therapeutic requirements of the exercise in question and evaluating the level of control that the game exacts on patient engagement (Pirovano et al. 2016). That is, ensuring that the game does not cause additional or renewed injury to the patient. In conveying exercise protocol to the game designers, health professionals indirectly also act as hardware consultants, in that a clearly defined protocol will make it apparent whether custom controllers are required or if standard game input devices will be sufficient for effective and relatively risk-free rehabilitation. Furthermore, unless artificial intelligence (AI) can be developed and trusted to such an extent that it is capable of leading patients through the different rehabilitation phases, health professionals must be at hand to provide both real-time and delayed feedback on the progress of patient rehabilitation – be it remotely or in person. Health professionals therefore play their roles during very distinct phases of development (Fig. 2), namely: (a) early design, where they convey the exercise requirements and advise on controller selection; (b) user testing, where they ensure the integrity of the therapy in question; and (c) implementation, where they guide patient progress.

With the emphasis on therapeutic accuracy, rehabilitation games often tend to relegate usability and (more so) user experience (UX) to triviality (Pirovano et al. 2016). In order to avoid the situation of an uninspiring – albeit remedially precise – rehabilitation game, enlisting the service of a UX expert should not be overlooked. Their part-to-play commences early in the context analysis phase with an ethnography study of the user. From here, the UX expert's level of activity decreases rapidly until the period preceding the first user tests, where their involvement peaks. Thereafter, UX expert participation gradually tapers down until diminishing entirely just prior to implementation (Fig. 2).

This leaves the technical team (game designer, programmers, visual and sound artists) to bring the rehabilitation requirements to life while keeping with a maximal UX. The technical team, with varying degrees of content-demand individual workloads, will be active from the very beginning of the project and well into the implementation phase where they will have rehabilitation game maintenance responsibilities (Fig. 2).

Usability and User Experience (UX)

Usability and UX are composed of an interplay between the three core elements of a rehabilitation game environment – the technical (or game) element, the patient (or player) element, and the professional therapy (or rehabilitation) element. It is up to the UX designer to ensure that the patient's attitudes and emotions about their therapy are attended to in a game that: (a) appropriately matches gameplay to the therapy context, and (b) caters to the patient's gameplay preferences and exercise habits. Consequently, in order to improve the game from the player's point of view, UX design and evaluation is interested in player perceptions and responses during and after play sessions. UX in games is described and measured through concepts such as immersion, engagement, presence, fun, and flow (Bernhaupt 2015). Successful UX design increases the attractiveness of rehabilitation games for potential users and maintains the motivation of current players.

Since rehabilitation games are purposed beyond the game context, usability is another fruitful design concept that ensures the hedonic aspects of the gaming experience do not overrule important rehabilitation design elements. Usability is concerned with the extent to which a user can use a system with effectiveness, efficiency, and satisfaction (ISO 1998). Where UX design is sensitive to patient health and well-being while continuously reinforcing a sense of achievement through an aesthetically pleasing game interface, usability highlights the more pragmatic aspects of rehabilitation games as a goal-oriented activity. For instance, usability addresses rehabilitation game relevant questions about controller suitability and feedback clarity from a patient perspective. Such usability measures can be used for assessing player understanding and interaction with the primary control mechanic (target rehabilitation movement) as well as their perceived

usefulness of the rehabilitation game. Negative controller experiences and misconstrued user interface communication will certainly cause patients to abandon continued use of rehabilitation games (Ravyse et al. 2017).

Common methods to collect user experiences and usability data throughout the rehabilitation game development cycle include playtests, live observations, interviews, questionnaires, and video and data logging. The route to positive UX begins by defining goals, desires, and target groups and continues with an iterative user-centered design (UCD) life cycle. Methods include focus groups, individual interviews, and personas. Persona descriptions attempt to clarify user preferences for free-form or instructed rehabilitation sessions, regular or periodical training intervals, self- or social competition, fictional or realistic game designs, and so forth. Despite the common goal to rehabilitate, personal goals may vary. Rehabilitation game designs should therefore implement features and settings that can be personalized (to some extent) before and during the different phases of the game's rehabilitation journey.

Application Areas

Rehabilitation takes place when the biomechanical, physiological, or neurological functioning of the human body is being restored to a former more functional state (Prentice and Kaminski 2004). Due to largely speculative evidence supporting game-based neurological forming and the limited success of games promoting participation in physical activity in pursuit of sound physiological functioning, the leading pragmatic use of rehabilitation games is to recover motor skills. Furthermore, rehabilitation games have a distinct operational phase within this physical rehabilitation process.

The pathway to biomechanical recovery either stems from surgery, diagnosis of disease affecting motor ability, or trauma resulting in injury. The latter may also require corrective surgery, complicating the recuperation pathway somewhat. No matter how complex the pathway, rehabilitation can be divided into phases with pain and phases that are relatively pain-free. The phases with pain are those immediately following the injury or trauma. The somewhat later, pain-free phases of rehabilitation, usually commence once range of motion has been re-established and is concerned with: firstly, depending on the body part to be rehabilitated, restoring proprioception and, secondly, reinstating strength and flexibility (Prentice and Kaminski 2004). Although academic experimentation with games that assist in giving back range of motion (i.e., in the phase with pain) are not uncommon, it is understandable that the larger corpus of rehabilitation games is confined to the seemingly lower risk pain-free phases. That is, the most widespread rehabilitation games are for proprioception, balance, strength, and flexibility. Another factor influencing the skewed spectrum of rehabilitation game application is implementation constraint.

Implementation

Pain-free rehabilitation offers two arenas. Patients can remain (whether by choice or prescription) within a healthcare facility or take their exercise regimes home. Healthcare facility rehabilitation falls under the premise of having a health professional available for corrective or supportive assistance when conducting the prescribed rehabilitation exercises. By extension, rehabilitation games can hence be played at a healthcare facility or at home. However, rehabilitation games at healthcare facilities, outside of academic experimentation, are uncommon. This is largely due to issues arising from physical setup, technical support necessities, and user engagement. The most common rehabilitation games are those involving motor skills and inevitably require motion tracking. With the exception of balance and proprioception games that are principally played on sensor boards, motion tracking involves the use of cameras. Such camera setups require significant space and precise location. Furthermore, the risk of occlusion (obscuring the camera view with a physical presence) makes that the space for motion tracking cannot be shared with other

activities. Although Xbox Kinect offers a relatively low-cost and minimal space requirement solution, the risk of occlusion remains, and behind-the-player-interference is a likely hindrance in active environments such as healthcare facilities. Both of these cause disrupted gameplay, resulting in disjointed user engagement with the game, leaving patients frustrated and generally disgruntled with the healthcare facility. Additionally, technical failure (hardware or software) is unavoidable when implementing a technology-based solution and as with occlusion, disruptive failure will run the same dissatisfied-patient course. To some extent, healthcare facilities could mitigate this through incurring the extra cost of having immediate technical support at hand. Considering the single-player-for-single-exercise designs of rehabilitation games, most healthcare facilities find it difficult to justify physical space and budget investment for motion tracking games.

As a homecare solution, budget (and most likely space too) limitations are even more profound than at healthcare facilities. This leaves home use of rehabilitation games in the hands of mainstream platforms such as Nintendo Wii and Xbox Kinect. There exists some evidence in favor of these platforms as out-of-the-box rehabilitation tools and although a meta-analysis of the Wii Fit series shows that it might have potential as a rehabilitation device, the limited number of randomized control trials suggests that research on this is inconclusive (Tripette et al. 2017). This is largely due to the clinical nature of rehabilitation, where control and form of movement are paramount. Kinect and Wii platforms were never intended for clinical rehabilitation and if pursuing strict movement analysis is critical, the development of custom controller hardware becomes obligatory. This does not mean that hardware such as the Kinect camera or Wii balance board, augmenting these popular platforms, is immediately refutable. Many successful musculoskeletal facilitation efforts couple these controllers to bespoke games that are aimed at late phase rehabilitation or other motor skill quality improvements that do not stem from direct physical trauma (e.g., cerebral palsy and Parkinson's disease) – making the Kinect camera and Wii balance board well suited to rehabilitation gameplay at home (Lange et al. 2009).

Home users of rehabilitation games most often perceive the games as virtual personal exercise professionals, positing some level of trust in their implementation (Lewis and Rosie 2012). As such, the actual game (or software) must essentially mimic the uncompromisable rehabilitation practices of constant patient progress monitoring and adjusting the rehabilitation program accordingly. Rehabilitation games satisfy this need by leveraging user profiling techniques with backend database systems that capture patient gameplay activity (Hocine et al. 2014). The activity is captured and translated into suitable metrics that represent the progress of the patient rehabilitation. The selected metric is heavily dependent on the target rehabilitation area and could include anything from stimuli reaction time to angle of flexion and time spent in target heart rate zone. Whatever the metrics of interest may be, they are customarily shared with the patient's health care professional, either in the form of Excel spreadsheets at the conclusion of an exercise session or a custom real-time dashboard. The healthcare professional then either provides immediate or delayed feedback built on the metrics they receive. Immediate feedback relies on real-time data and a direct communication (usually chat) interface. The captured metrics also serve as input for an artificial intelligence (AI) technique called dynamic difficulty adjustment (DDA). DDA occurs when the game, based on algorithmic understanding of the key performance metrics, automatically increases or decreases the gameplay difficulty level in real time – akin to increasing the lifting weight as the patient becomes stronger. As an extension to DDA, camera-based rehabilitation games can benefit from automatic affect recognition based on body movements (Kleinsmith and Bianchi-Berthouze 2013). While DDA has the overall consignment of maintaining flow in rehabilitation games, body movement monitoring ensures that patients do not falter in their rehabilitation movements and can be used to map body posture to

player emotion – answering the all-important question of motivation.

Conclusion

Rehabilitation games work under experimental conditions, and with widespread adoption of rehabilitation games in the hands of homecare (as opposed to healthcare facilities), the focus should be on making games that do not rely on an overemphasis of control accuracy. Motivating the player (or patient) to set up a home rehabilitation gaming environment may essentially stem from the desire to rehabilitate, but custom controllers will place rehabilitation games out of the home consumer's reach in both price and availability. The game context therefore becomes a key success driver behind pervasive use of rehabilitation games and should distance itself from merely grinding through exercise regimes – a home gym can also do this. Rehabilitation games should thus avoid the fallacy of many serious games and instead be set against the backdrop of an alluring narrative with believable non-player character AI.

Sustained engagement with rehabilitation games goes beyond good game design. An equal amount of merit lies in applying sound usability and UX design principles. The reward for such efforts is an emotionally and physically pleasant game that patients will continue playing, rather than seeking other rehabilitation options, potentially lengthening their play sessions and ultimately improving their rehabilitation results.

Currently, improved rehabilitation is the primary responsibility of rehabilitation game AI. DDA and affect recognition manipulate the game's physical interface by altering the patient's physical interaction intensity. Although these AI techniques support the maintenance of flow theory in games, the intrinsic motivation to persist with rehabilitation activities, however, rests in a different space of the psychological realm. Affect recognition has made some progress towards mapping player posture to emotion but has yet to translate this into suitable game response. Having AI that operates, not only on a physical level but also on a psychological level, will make significant strides toward making rehabilitation games truly become the motivational tools they were intended to be.

Cross-References

- ▶ Gamification
- ▶ Motivation
- ▶ Rehabilitation
- ▶ Serious Games
- ▶ Usability

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Reinforcement Learning

▶ Deep Reinforcement Learning in Virtual Environments
▶ Machine Learning for Computer Games

Render

▶ 3D-Rendered Images and Their Application in the Interior Design

Rendering

▶ Rendering Equation

Rendering Equation

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Synonyms

Digital image; Global illumination; Rendering

Definitions

Global Illumination	Global interaction between the light sources and the surfaces of environment.
Pixel	Abbreviation of the English term picture element.
Radiative Transport	Area that studies the interaction of radiant energy with matter, on a macroscopic scale.
Transference Equation	Integral-differential equation that describes the interaction of light with the participant medium and, given the appropriate boundary conditions, its interaction with arbitrary surfaces.
Transport Theory	Field that embraces all macroscopic phenomena that result from the interaction of infinitesimal particles with the medium. Macroscopic behavior of photons, neutrons, and gas molecules are all within their scope.

Introduction

The basic and fundamental problem of Computer Graphics is to transform data into image. Digital image is the result of most of the processes involved in computer graphics. A mathematical model to describe an image is a function defined in a two-dimensional surface with values in a color space (Gomes and Velho 2008). In this way, this surface is represented by a matrix *row* × *column*, where the number of rows is the vertical resolution and the number of columns the horizontal resolution of the image. Each array's element is called the pixel of the image. And each pixel stores a color value as information.

In computer graphics, visualization is completed by assigning color information to the objects represented in the image. This process is called color and shading. In the case of three-dimensional scenes, it is natural that one chooses to obtain this information by lighting calculation, since the physiological process of human vision occurs through the interaction of light with

objects. Color is a sensation caused by light and perceived by the eyes. In this way, one only perceives colors where the light arrives (Rogers 1998).

The illumination of a 3*D* scene is the result of global interaction between the light sources and the surfaces of environment. Such interaction is called global illumination, a theme of great interest in the search for techniques that allow to simulate the phenomenology of light through physical concepts with the aim of generating synthetic images. The simulation is physics based to achieve the appearance of a hypothetical scene as real as possible. One of the problems encountered in global lighting techniques lies in its computational complexity, since all on-scene objects can interact with each other through light scattering (Arvo 1993).

Global illumination can be seen as a subarea of Radiative Transport, an area that studies the interaction of radiant energy with matter, on a macroscopic scale (Gomes and Velho 2008; Arvo 1993). The radiative transport theory origin, according to Arvo (1993), is attributed to the astrophysical works of Schuster and Schwarzschild (Schuster 1905; Schwarzschild 1906). Since then, this theory has been applied in many areas, such as computer graphics. It is based on the transference equation, an integral-differential equation that describes the interaction of light with the participant medium and, given the appropriate boundary conditions, its interaction with arbitrary surfaces. In addition, global illumination can also be seen as a branch of the Transport Theory (Byron Bird et al. 1960), a field that embraces all macroscopic phenomena that result from the interaction of infinitesimal particles with the medium. Macroscopic behavior of photons, neutrons, and gas molecules are all within their scope. The central equation of the theory of transport is known as the Boltzmann equation (Arvo 1993).

Fundamentals

Lighting is the study of propagation of light in the environment and its interaction with surfaces. A 3*D* scene is composed of objects that emit, reflect, or transmit light energy. According to physics, this light energy behaves as much as particle beam as a wave. The corpuscular model of light postulates that energy flow along a ray is quantized by moving particles called photons. In contrast, the wave model of light describes the light energy by combining the electric field with the magnetic field (Gomes and Velho 2008).

In most problems of light propagation in computer graphics, the interest lies in the illumination of a hypothetical scenario. In order to obtain an illumination equation, it is necessary to establish a physic-mathematical model of light propagation phenomenon. There are three possible models corresponding to three distinct areas, namely, geometric optics, physical optics, and radiative transport (Gomes and Velho 2008; Arvo 1993).

Geometric optics assume that light propagates straight at a constant velocity and models the interaction of that propagation on the surfaces of separation between two media (assuming that those surfaces are optically perfect). It adequately describes the macroscopic effects of light energy transport, such as linear propagation, reflection, and refraction, but does not take into account the concepts of radiometry that allow quantification and measurement of the quantities involved.

Physical optics extends geometric optics by incorporating modeling with Maxwell's equations. In addition to the classical phenomena, it allows the modeling of other phenomena such as scattering, interference, and diffraction, which occur when the scale of scene geometry is less than the wavelength of transported light.

For global illumination, it is necessary to model visual phenomena, that is, observable phenomena through the vision process or some equipment capable of perceiving luminous frequency and intensity. Radiative transport solves the illumination problem as transport of radiant energy. It essentially combines the theory of geometrical optics with thermodynamics. It is a more suitable model for the purposes of image synthesis.

Particle Model

Macroscopic phenomena modeled by radiative transport take into account the particle model of light. In this way, there is a relation with the

photon transport, an area that deals with the macroscopic statistical behavior of particles (Arvo 1993). This simplified light model captures the spirit of transport theory, whose goal is to determine the distribution of particles in space and time, taking into account their movement and interaction with the environment. Transport theory requires assumptions about the nature of particles. The two most important hypotheses are:

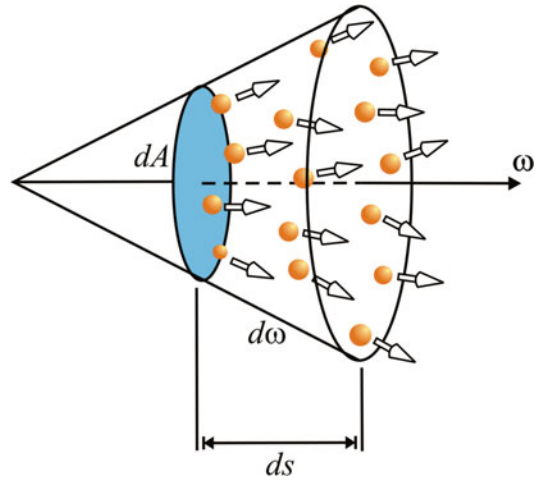
(i) The particles are so small and numerous that their statistical distribution can be treated as continuous.
(ii) At any point in time a particle is completely characterized by its position and velocity and by internal states such as polarization, frequency rate, or spin.

These hypotheses lead to the notion of phase space, an abstraction for dealing with particle configurations. Each dimension of the phase space represents a degree of particle freedom (usually six in total). For the sake of simplicity, the particles are considered to move at a constant speed c and have no internal states. According to Arvo (1993), this simplification corresponds to mono-energy radiative transfer, or mono-velocity transport to generic particles. The hypothesis of velocity requires only five degrees of freedom per particle, being three for the position and two for the direction. The 5-dimensional phase space is defined by the Cartesian product $\mathbb{R}^3 \times S^2$, where $\mathbb{R}^3$ is the $3D$ Euclidean space and S^2 is unit sphere in $\mathbb{R}^3$.

In order to characterize a particle configuration, it is necessary to specify all the degrees of freedom of each particle at each time instant, which corresponds to discrete points in the phase space. Analogously, it is possible to relate this discrete configuration to a continuous particle configuration, called phase space density, denoted by:

$$n(x, \omega, t)drd\omega. \tag{1}$$

The expression (1) represents the number of particles in a differential volume dr over the point $x \in \mathbb{R}^3$ that moves in a direction defined by the differential solid angle $d\omega$, $\omega \in S^2$ at the instant t. Its unit of measure is given by $m^{-3}sr^{-1}$. Note



Rendering Equation, Fig. 1 Flow in phase space

that the phase space density makes no mention of material-related attributes such as mass or energy. These concepts only appear when physical meanings are related to the studied particles. This abstract nature of the phase space density makes possible its use in almost every type of particle transport problem (Arvo 1993).

Generally it is convenient to characterize the particles density by flow through a real or imaginary surface. Consider the particles that cross a differential area dA with directions along the differential solid angle $d\boldsymbol{\omega}$ relative to the surface normal, at the time instant t. The particles are within the volume element $dAds$, where $ds = cdt$, as illustrated by Fig. 1. Assuming that x is a point inside the volume element, the number of particles is given by:

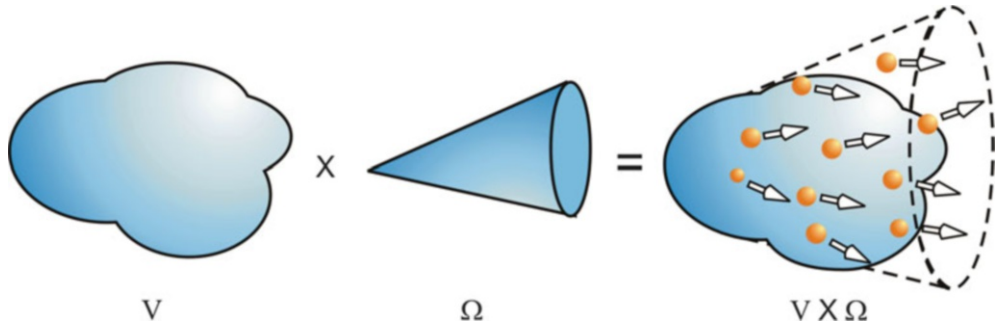
$$n(x, \omega)dAdsd\omega. \tag{2}$$

As $ds = cdt$, then:

$$cn(x, \omega)dAdtd\omega. \tag{3}$$

Particle Balance Equation

This section used as its main reference the Arvo work (Arvo 1993) and aims to derive a balance equation for particles that do not interact with each other. It is a widely used equation in Radiation Transport. It is an Eulerian derivation, since it takes into account a fixed reference.



Rendering Equation, Fig. 2 Phase space

Particles contained in some fixed volume in the phase space are considered. In this way, $V \subset \mathbb{R}^3$ is an arbitrary volume, $\Omega \subset S^2$ is an arbitrary solid angle, and consider the phase space defined by the Cartesian product $V \times \Omega$. This space contains all pairs (r, ω), such that $r \in V$ and $\omega \in \Omega$, as illustrated in Fig. 2.

The goal is to determine how the set of particles in $V \times \Omega$ changes over time. At any time t, the number of particles in this volume $(N(t))$ can be obtained by integrating the phase space density (given by the Eq. 1) in the volume:

$$N(t) = \int_{\Omega}\int_{V} n(r, \omega, t)\, dr d\omega, \tag{4}$$

which results in a dimensionless quantity.

Once the particles number in the volume of interest is obtained, their variation in time is analyzed. In general, the particles number in a given volume may change over time due to the properties of medium and time-dependent sources or due to transient effects as the system progresses in search of equilibrium. However, one only has to consider stationary distributions, since the speed of light is extremely fast. In this way, it is possible to assume that the equilibrium is reached instantaneously with respect to the geometric configuration of the environment at any instant of time.

Each volume then has a fixed number of particles, which implies that the phase space flux is independent of time, $\Phi = \Phi(r, \omega)$. Thus:

$$\frac{dN(t)}{dt} = 0. \tag{5}$$

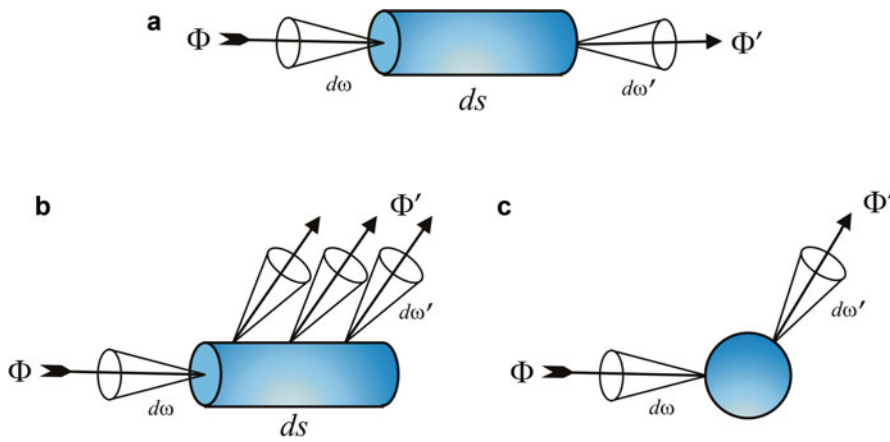
Even in the stationary case, time is evident in the constant movement of particles, implying that equilibrium is dynamic. The inflow and outflow of the volume must be in equilibrium, and to examine this balance it is necessary to identify the possible physical processes for which N can change. Each of the processes, namely emission, transmission, and collision, can change the number of particles in the volume. In this way, it is necessary that:

$$\begin{bmatrix}\text{Changes}\\ \text{due}\\ \text{Emission}\end{bmatrix} + \begin{bmatrix}\text{Changes}\\ \text{due to}\\ \text{Transmission}\end{bmatrix} + \begin{bmatrix}\text{Changes}\\ \text{due to}\\ \text{Collision}\end{bmatrix} = 0. \tag{6}$$

We will name the first term, *Changes Due to Emission,* for M_E. This term refers to generation of new particles through sources. It is assumed that there are one or more physical processes generating new particles and their combined effects are described by a source function (q) of phase space, defined in $\mathbb{R}^3 \times S^2$. This function gives the number of particles generated per unit volume, per unit of solid angle, and per unit time. Thus, its unit of measure is given by $m^{-3}sr^{-1}s^{-1}$. In terms of q, the change in N due to emission is given by:

$$M_E \equiv \int_{\Omega}\int_{V} q(r, \omega)\ \ dr d\omega, \tag{7}$$

and its unit of measure is s^{-1}.



Rendering Equation, Fig. 3 An intuitive view of volumetric interactions

We will name the second term, *Changes due to Transmission,* by M_T. This term refers to particles with directions in Ω that escape from or enter the volume V due to transmission. More precisely, transmission (or leakage) is the flow of particles passing through the surface ∂V of volume V. The leakage through each differential element of the surface depends only on the flow component that is normal to the surface. Integrating the normal component of the flux of particles in Ω over the entire surface ∂V gives:

$$M_T \equiv \int_{\Omega}\int_{\partial V} \Phi(s,\omega)\omega \cdot \mathbf{n}(s)\ \ drd\omega, \qquad (8)$$

and its unit of measure is s^{-1}. In general, some differential elements of the surface have positive flow and some negative flow, that is, M_T deals with particles entering and leaving the volume.

The third and last term, *Changes due to Collision*, is divided into two: absorption and scattering. As stated at the beginning of this section, it is assumed that the particles interact only with the environment, but do not interact with each other, which makes the collision rate independent of the flow.

It is assumed that the probability of particles disappearing due to absorption is proportional to the distance of displacement through the medium, as illustrated by Fig. 3a. The proportionality constant is called the *absorption coefficient* (σ_a), whose unit of measure is m^{-1}. This coefficient may vary with position, but is usually assumed to be independent of direction. This is equivalent to assuming that the medium is isotropic. The change in N due to absorption is given by:

$$C_{abs} = \int_{\Omega}\int_{V} \sigma_a(r)\Phi(r,\omega)drd\omega. \qquad (9)$$

Collisions due to scattering are more complex. As with absorption, the probability of a collision due to scattering occurs is proportional to the displacement distance of the particle. After collision, however, the new direction must be taken into account. Because of the hypothesis that particles move at a constant velocity, we need to consider other changes to the particles as a result of scattering.

The scattering process is characterized by the *volumetric scattering nucleus* (k). The function k is defined in $\mathbb{R}^3 \times [-1, 1]$, such that the probability of a particle r moving in a direction ω deflect to the new direction ω' (per unit of solid angle, per unit of displacement) is given by:

$$k(r; \omega \cdot \omega')\, drd\omega', \qquad (10)$$

and its unit of measure is $m^{-1}sr^{-1}$. Figure 3b illustrates this concept. The fact that k depends only on the scalar product $\omega \cdot \omega'$ and not from the individual directions confirms once again the isotropy of the medium.

Scattering can remove particles of $V \times \Omega$ through a process called *out-scatter*. In this process, the particle remains at V while its direction is instantly modified to something outside Ω, due to collision. To consider out-scatter, it is defined the total number of collisions due to scattering suffered by the particles in $V \times \Omega$ per unit time, given by:

$$C_{\text{out}} \equiv \int_{\Omega}\int_{V}\int_{S^2} k(r;\omega\cdot\omega')\Phi(r,\omega)d\omega' dr d\omega. \tag{11}$$

The opposite process to out-scatter is a process in which particles are added in $V \times \Omega$ because they have been deflected into the volume. This process is called *inscatter* and is defined as the number of particles in V, per unit time, with directions of displacement in Ω after scattering. It is given by:

$$C_{\text{in}} \equiv \int_{\Omega}\int_{V}\int_{S^2} k(r;\omega'\cdot\omega)\Phi(r,\omega')d\omega' dr d\omega. \tag{12}$$

Note that both C_{out} and C_{in} deal with particles whose directions are defined in Ω before and after scattering, which does not imply loss or gain. However, it is only necessary to consider the change due to scattering, which is defined by the difference between C_{in} and C_{out}. Once we have defined all the terms involved in the balance Eq. 6, we can now group the terms corresponding to the five physical processes capable of modifying N, separating into losses and gains:

$$\underbrace{M_T + C_{abs} + C_{\text{out}}}_{\text{losses}} = \underbrace{M_E + C_{\text{in}}}_{\text{gains}} \tag{13}$$

To extract the global balance equation from (13), it is necessary to eliminate the references to the fixed sets V and Ω. Note that all terms minus one of the Eq. 13 imply integration into V, only the term M_T is expressed as an integral in ∂V. In this way, it is possible to use the Gauss Theorem to convert it into a volume integral:

$$M_T \equiv \int_{\Omega}\int_{V} \omega\cdot\nabla\Phi(r,\omega)dr d\omega. \tag{14}$$

In addition to the Gauss Theorem, we also used the identity:

$$\nabla\cdot[\omega\Phi(r,\omega)] = \omega\cdot\nabla\Phi(r,\omega). \tag{15}$$

With the new expression for M_T, all terms in the Eq. 13 imply integration over V and Ω. However, the initial hypothesis was that $V \times \Omega$ is arbitrary, which allows to extract integrands:

$$\begin{aligned}&\omega\cdot\nabla\Phi(r,\omega) + \sigma_a(r)\Phi(r,\omega)\\ &+\int_{S^2} k(r;\ \ \omega\cdot\omega')\Phi(r,\omega)d\omega' = q(r,\omega)\\ &+\int_{S^2} k(r;\ \ \omega'\cdot\omega)\Phi(r,\omega')d\omega'.\end{aligned} \tag{16}$$

The integral corresponding to term C_{out} on the left side of the above equation can be simplified, since the Φ function does not depend on the integration variable. In this way, we introduce the *scattering coefficient* (σ_s), which is the probability of a particle suffering a scatter collision per unit of displacement, defined by:

$$\sigma_s(r) \equiv \int_{S^2} k(r;\omega_o\cdot\omega')d\omega', \tag{17}$$

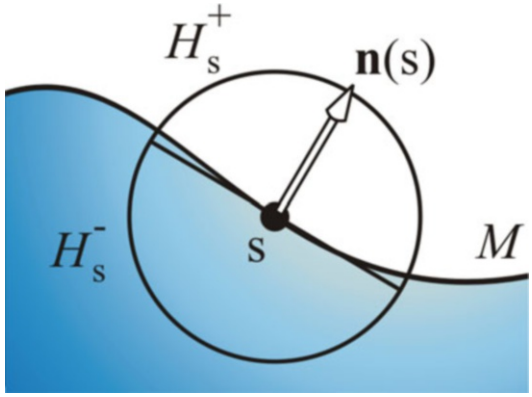
and its unit of measure is m^{-1}. The direction ω_o may be arbitrary in S^2 due to isotropy. In this way, σ_s becomes a factor of Φ in the balance equation.

In this way, replacing the new notations in the Eq. 16, we have:

$$\begin{aligned}&\omega\cdot\nabla\Phi(r,\omega) + \sigma_a(r)\Phi(r,\omega)\\ &+\sigma_s(r)\Phi(r,\omega) = q(r,\omega)\\ &+\int_{S^2} k(r;\omega'\cdot\omega)\Phi(r,\omega')d\omega'.\end{aligned} \tag{18}$$

The two factors, σ_s and σ_a, can be grouped into a *total interaction coefficient* o, which is the probability of a particle suffering the two types of collision, per unit of displacement, and is given by:

$$\sigma(r) \equiv \sigma_s(r) + \sigma_a(r), \tag{19}$$



Rendering Equation, Fig. 4 Partition of surface M

And its unit of measure is m^{-1}. Substituting in the Eq. 18, we have:

$$\omega \cdot \nabla \Phi(r,\omega) + \sigma(r)\Phi(r,\omega) = q(r,\omega) + \int_{S^2} k(r;\omega' \cdot m)\Phi(r,\omega')d\omega' \quad (20)$$

The Eq. 20 is an integral-differential equation for the transport of stationary particles in monovelocity. When time-dependent phenomena are considered, the phase space flux is a function of time, $\Phi = \Phi(r, \omega, t)$, and an additional term appears on the left side of the Eq. 20:

$$\frac{1}{c}\frac{\partial \Phi(r,\ \omega,\ t)}{\partial t}, \quad (21)$$

where c is the particle velocity.

Boundary Conditions

In this section, we evaluate the boundary conditions for the Eq. 20. It is necessary to verify what happens in the surfaces, collectively denominated M. Each point on the surface M imposes a natural partition of S^2 on two hemispheres, as illustrated in Fig. 4.

Let $\mathbf{n}(s)$ be the normal vector on the surface at point $s \in M$. It is defined as *positive hemisphere* where $\mathbf{n}(s) \cdot \omega > 0$, giving the set:

$$H_s^+ \equiv \{\omega \in S^2 : \omega \cdot \mathbf{n}(s) \geq 0\}. \quad (22)$$

Similarly, we define the collection of every pair (s, ω) corresponding to the rays originating in M and pointing off the surface:

$$H^+ \equiv \{(s,\omega) \in M \times S^2 : \omega \in H_s^+\}. \quad (23)$$

The *negative hemisphere* H_s^- and the set H^- are analogously defined, satisfying:

$$H_s^+ \cup H_s^- = S^2$$
$$H^+ \cup H^- = M \times S^2.$$

The explicit boundary condition is independent of the flow Φ, taking into account particles that are generated by independent processes and subsequently enter the system across boundaries. It is given by:

$$\Phi(s,\omega) = q_b(s,\omega), \quad \forall (s,\omega) \in H^+. \quad (24)$$

There are two types of *implicit boundary conditions*. The first is due to *specular reflection,* given by:

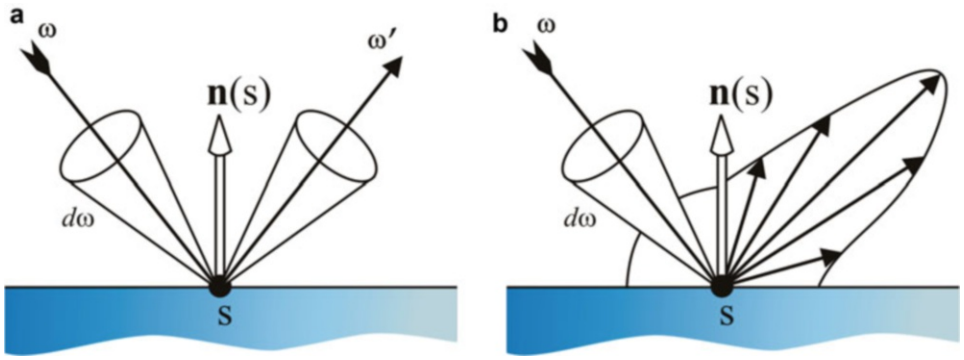
$$\Phi(s,\omega) = F(s,-\omega')\Phi(s,-\omega'), \quad (25)$$

where ω' is reflection direction of ω around normal surface in s.

The second type is given by an integral transformation that expresses the reflected density of particles in any direction as a weighted sum of incident densities, and the weight factor strongly depends on both directions. This phenomenon is also known as *diffuse directional reflection*, given by:

$$\Phi(s,\omega) = \int_{H_s^-} k_b(s;\omega' \rightarrow \omega)\Phi(s,\ \omega')d\omega', \quad (26)$$

where k_b is the surface scattering core with sr^{-1} unit of measure. The $\omega' \rightarrow \omega$ notation indicates incident and reflected directions. The following Fig. 5 illustrates the implicit boundary conditions.



Rendering Equation, Fig. 5 Two types of implicit boundary conditions: (**a**) specular reflection and (**b**) diffuse directional reflection

Radiometry

Radiometry provides a set of ideas and mathematical tools to describe the propagation and reflection of light (Pharr and Humphreys 2004). It deals with the measurement of various physical quantities related to the transport of radiant energy. The letter Q is used to represent the radiant energy, which is measured in Joules (J). The main radiometric quantities are: *radiant power* (or flux), *radiance, irradiance, radiosity,* and *intensity.*

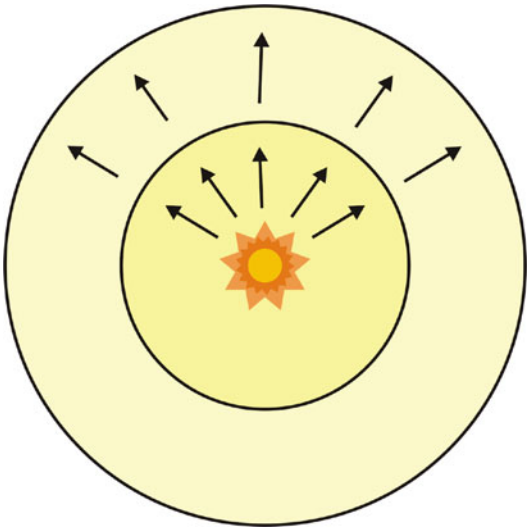
This section used as main reference the works (Gomes and Velho 2008; Pharr and Humphreys 2004), and its purpose is to report the properties of each radiometric quantity mentioned above. The Appendix A brings important mathematical concepts to the study of radiometry.

Radiant Power

The propagation of light occurs at a very high speed. In this way, it becomes more appropriate to think in terms of flow. Radiant power (Φ) (or flow) measures the rate of radiant energy flowing through a surface per unit time:

$$\Phi = \frac{dQ}{dt}. \tag{27}$$

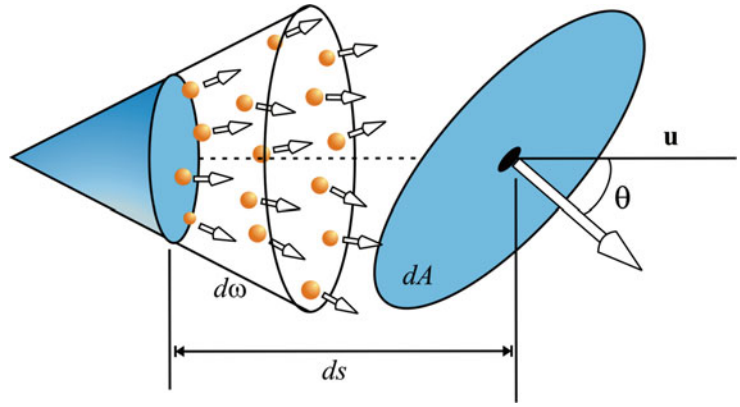
The magnitude called radiant power is measured in Watt ($1w = 1J/s$). The total emission of light sources is usually measured in terms of flow. Figure 6 illustrates the flow of a punctual light source measured by the total amount of energy that passes through an imaginary sphere around the light. It is interesting to note that the total amount of flow measured in both spheres is the same. It is also important to measure the flow per unit area. This magnitude is called flux density and is measured in w/m^2.



Rendering Equation, Fig. 6 Radiant power (or flow) from a punctual light source

Radiance

Consider a photon beam that flow in direction **u** through the surface element dA confined in the



Rendering Equation, Fig. 7 Photon beam in the volume element *dAds*

solid angle element $d\omega$. It is assumed that all photons are contained in the spatial volume element $dAds$, where $ds = cdt$, with c the photons velocity. Figure 7 illustrates the situation.

In previous sections, a particle model was introduced, where the number of particles in the phase space volume element is given by the expression (3). In addition, from what is presented in Appendix A, the projected area will be given by the expression (73), which gives $dA = dAcos\theta$. Each photon has an energy given by $\hbar v$, where $\hbar$ is the *Planck constant,* and v is the photon frequency. Therefore, the radiant energy carried by the photons in the volume element $dAcos\theta dmds$ is given by:

$$\hbar vcn(x, \mathbf{u}) dAcos\theta d\omega dt. \tag{28}$$

The radiant energy element dQ carried in the volume element $dAcos\theta d\omega$ is obtained by integrating the expression (28) into the phase space:

$$dQ = \left(\int_{\omega} \int_{A} \hbar vcn(x, \ \mathbf{u}) aAcos\theta d\omega \right) dt. \tag{29}$$

It is concluded that the radiant power is given by:

$$\phi = \frac{dQ}{dt} = \int_{\omega} \int_{A} \hbar vcn(x, \mathbf{u}) dAcos\theta d\omega, \tag{30}$$

and therefore:

$$\frac{d^2\phi}{dAcos\theta d\omega} = \hbar vcn(x, \ \mathbf{u}). \tag{31}$$

The magnitude of the Eq. 31 is called *radiance* and is indicated by the symbol L. In this way:

$$L = \frac{d^2\phi}{dAcos\theta d\omega} \ \Leftrightarrow \ d^2\phi = LdAcos\theta d\omega. \tag{32}$$

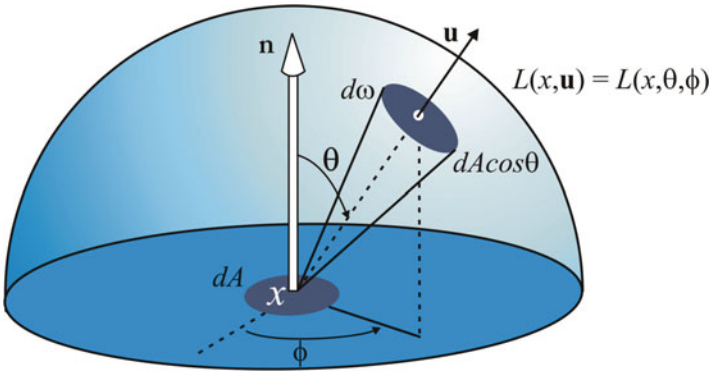
The unit of radiance is w/m^2sr. From the definition of radiance we have that:

$$L = \frac{d}{d\omega} \left(\frac{d\phi}{dAcos\theta} \right). \tag{33}$$

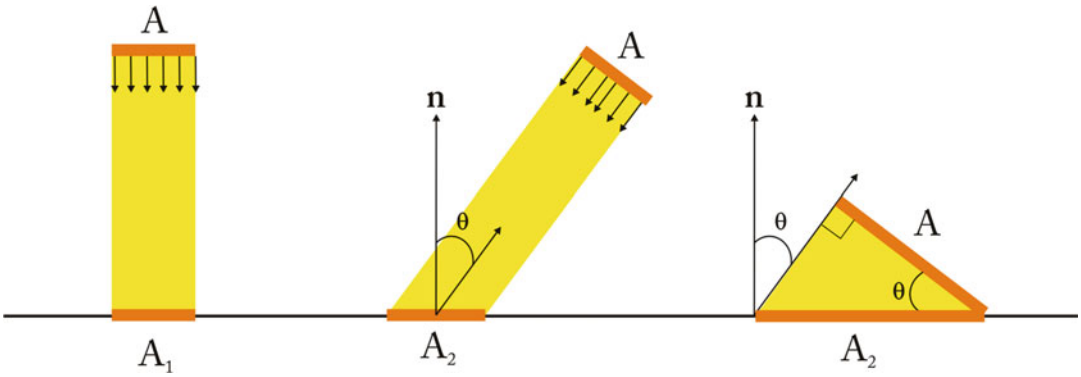
The expression in parentheses measures the density of radiant power ϕ on the projected surface in the normal direction. Therefore, radiance measures the radiant power density variation relative to the solid angle in a given direction.

More precisely, if $x \in \mathbb{R}^3$ is a point of space on a surface S and $\mathbf{u}$ is a direction, the radiance $L(x, \mathbf{u})$ is the flow at point x per unit of perpendicular area to $\mathbf{u}$ (i.e., projected area in propagation direction), and per unit of solid angle. Figure 8 illustrates the concept.

Integrating the expression $d^2\phi = LdAcos\theta d\omega$, given by the Eq. 32, in a given region R on a surface (integral in dA), and in the corresponding solid angle region (integral in $d\omega$), we obtain the total flux of radiant energy emitted by the region R within the specified solid angle. Further, by integrating the same expression with respect to the solid angle element throughout the upper hemisphere Ω, one obtains:



Rendering Equation, Fig. 8 Radiance emitted by a surface



Rendering Equation, Fig. 9 Lambert's Law

$$d\Phi = \left(\int_{\Omega} L(x, \ \theta, \phi) cos\theta d\omega \right) \ dA, \qquad (34)$$

or yet:

$$\frac{d\Phi}{dA} = \int_{\Omega} L(x, \ \theta, \phi) cos\theta d\omega, \qquad (35)$$

which is an expression for radiant power density throughout the upper hemisphere of the surface.

Irradiance and Radiosity

The radiometric magnitude *irradiance* (E) defines the incoming flux on a given surface through a given direction (flow per area unit). Irradiance is measured in w/m^2. Analyzing Fig. 6, while the flow has same measure in both spheres, the irradiance is smaller as the radius of sphere increases, because the area becomes larger. In particular, for sphere whose radius is given by r:

$$E = \frac{\Phi}{4\pi r^2}. \qquad (36)$$

The irradiance equation allows us to understand Lambert's Law, which says that the amount of light that arrives on a surface is proportional to the cosine of angle formed between the incident light direction and the vector normal to the surface.

According to the left side of Fig. 9, consider a light source with area A and flow Φ, whose direction incident on a given surface makes 0 with normal. The illuminated area A_1 of the surface is equal to the area A of the light source. Thus, the irradiance at any point in A_1 is given by:

$$E_1 = \frac{\Phi}{A}. \qquad (37)$$

Now consider the central part of Fig. 9, where the incident direction of light makes an angle θ with the normal. In this case, the illuminated area A_2 of the surface is greater than the area A of the light source and can be approximated by $A/cos\theta$ (as illustrated by the right side of Fig. 9). Thus, the irradiance at any point in A_2 is given by:

$$E_2 = \frac{\Phi cos\theta}{A}. \tag{38}$$

Generalizing, given a point x on a surface A and a direction $\mathbf{u} = (\theta_i, \phi_i)$ (where the subindex i indicates quantities associated with radiant energy entering the upper hemisphere of illumination), the *irradiance* E in x in direction $\mathbf{u}$ is the total flux density incident on the surface in specified direction. Using the Eq. 35 one has:

$$E = \frac{d\Phi}{dA} = \int_{\Omega} L_i(x, \ \theta, \phi) cos\theta d\omega. \tag{39}$$

This equation states that the total flux density incident on the surface is the integral of incident radiance in the direction $\mathbf{u}$ over the entire upper hemisphere. In particular, using spherical coordinates in the upper hemisphere, we obtain through the relation given by the Eq. 77:

$$\begin{aligned} E &= \int_{\Omega} L_i(x, \theta, \phi) cos\theta d\omega \\ &= \int_0^{\pi} \int_0^{2\pi} L_i(x, \theta, \phi) cos\theta sen\theta d\theta d\phi. \end{aligned} \tag{40}$$

Deriving the Eq. 39 with respect to the solid angle ω gives:

$$\begin{aligned} \frac{dE}{d\omega} &= L(x, \theta, \phi) cos\theta \Rightarrow dE \\ &= L(x, \theta, \phi) cos\theta d\omega. \end{aligned} \tag{41}$$

Radiosity defines the flux leaving a surface in a given direction. The radiosity B at a given point x of a surface in a direction (θ_o, ϕ_o) (where the subindex o indicates quantities associated with the radiant energy leaving the upper hemisphere of illumination) is the flux density emanating from the surface at point x, in the specified direction. Equivalent to the above irradiance equations, we have that:

$$B = \frac{d\Phi}{dA} = \int_{\Omega} L_o(x, \ \theta, \phi) cos\theta d\omega. \tag{42}$$

Using the expression of the solid angle element in the sphere (Eq. 77) we obtain:

$$\begin{aligned} B &= \int_{\Omega} L_o(x, \ \theta, \phi) cos\theta d\omega \\ &= \int_0^{\pi} \int_0^{2\pi} L_o(x, \ \theta, \phi) cos\theta sen\theta d\theta d\phi. \end{aligned} \tag{43}$$

Radiant Intensity

Radiant intensity I is the radiant flux emitted in a certain direction, which can be measured by the infinitesimal radiant flux in a given element of solid angle:

$$I = \frac{d\phi}{d\omega}. \tag{44}$$

The unit of measure is *w/sr*. Intensity describes the directional distribution of light and has meaning only for punctual light sources.

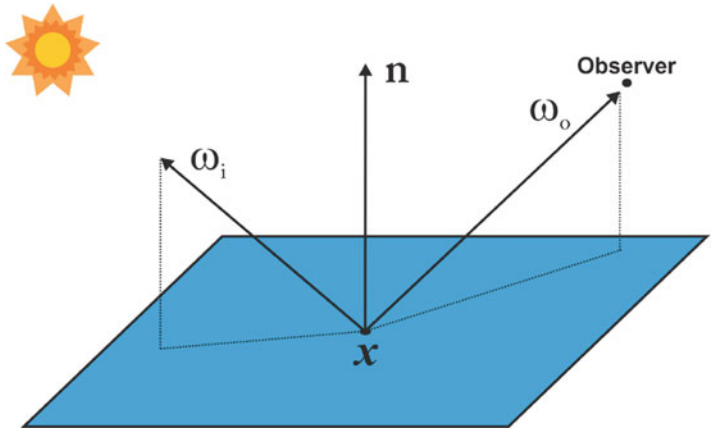
Now consider a surface located at a distance d from the light source so that its normal vector makes an angle θ with the direction of illumination. The solid angle element of this surface is given by $d\omega = dAcos\theta/r^2$. If E is the irradiance in the area element dA of the surface, we have that:

$$E = \frac{d\phi}{dA} = \frac{d\phi cos\theta}{r^2 d\omega} = \frac{1}{r^2} \frac{d\phi cos\theta}{d\omega} = \frac{I cos\theta}{d^2}. \tag{45}$$

This is the law of attenuation of radiant intensity with the square of distance.

Bidirectional Reflectance Distribution Function (BRDF)

In the physical world, objects have a different appearance when viewed from different positions, illuminated with light sources coming from different directions, or even with lights of different colors or intensities. In order to represent the process of illumination through the computer, it



Rendering Equation, Fig. 10 Incident and reflected flow in an element of area

is also necessary to understand these phenomena and to search for mathematical models that allow the simulation of these light-object interactions.

Among the main elements that influence the radiance emitted by a surface S, the main ones are: lighting, surface reflectance properties, and position of the observer. For simplicity, it is assumed that the medium of propagation is nonparticipative.

The bidirectional reflectance distribution function (BRDF) relates the incident energy in a point x with the reflected energy. Consider the configuration of Fig. 10. We want to know how much radiance leaves the surface in the direction ω_o towards the observer, denoted by $L_o(x, \omega_o)$, resulting from the radiance incident along the direction ft toward the surface, denoted by $L_i(x, \omega_i)$.

Considering the direction ω_i, as a cone of differential directions, the differential radiance in x is given by:

$$dE(x, \omega_i) = L_i(x, \ \omega_i) \cos\theta_i d\omega_i. \tag{46}$$

An amount of differential radiance will be reflected in the direction ω_o due to irradiance. The model of geometric optics provides some hypotheses about the behavior of light (Pharr and Humphreys 2004). The linearity hypothesis is one of them and says that the combined effect of two input data on an optical system is always equal to the sum of effects of each input data individually. Thus, by the hypothesis of the linearity of geometric optics, the reflected differential radiance is proportional to the irradiance:

$$dL_o(x, O_o) \propto dE(x, \omega_i). \tag{47}$$

The proportionality constant defines the BRDF of the surface in particular for the pair of directions ω_i and ω_o. The BRDF is defined by the quotient between radiance of the reflected flux and the irradiance of incident flux:

$$f_r(x, \ \omega_i, \ \omega_o) = \frac{dL_o(x, \ \omega_o)}{dE(x, \ \omega_i)} = \frac{dL_o(x, \ \omega_o)}{L_i(x, \ \omega_i) \cos\theta_i d\omega_i}. \tag{48}$$

BRDF provides a way to quantitatively express the connection between the irradiance (incident flux per unit area) and the radiance (incident flux per unit area per unit of solid angle) reflected by the surface. For simplicity, it is assumed that the point of reflection is equal to the point of incidence x (there is no phenomenon of scattering) and that the irradiance depends only on the direction of incidence (θ_i, ϕ_i). Thus, the BRDF depends only on the incidence and reflection directions (hence the bi-directional adjective in the name):

$$f_r = f_r(x, \theta_i, \phi_i, \theta_o, \phi_o) = f_r(x, \omega_i, \omega_o). \tag{49}$$

By definition, L_o is smaller than L_i, except in cases where the surface is a light source. However, the cosine factor in denominator in Eq. 48 causes the BRDF not to be limited in the range [0, 1], being able to assume arbitrarily large values. Note that from Eq. 48 we have:

$$\frac{dL_o(x,\omega_o)}{dL_i(x,\omega_i)} = fr(x,\omega_i,\omega_o)cos\theta d\omega_i$$
$$= fr(x,\omega_i,\omega_o)\mathbf{n},\omega_i d\omega_i. \quad (50)$$

As the total radiance leaving the upper hemisphere is less than or equal to the radiance entering that hemisphere, integrating both members of this equation throughout the upper hemisphere Ω concludes that:

$$\int_{\Omega} f_r(x,\omega_i,\omega_o)\mathbf{n},\omega_i \ d\omega_i \leq 1. \quad (51)$$

This inequality is called the *BRDF energy conservation law*. It states that the total energy reflected in the upper hemisphere cannot exceed the total incident energy. In addition, the BRDF is reciprocal, that is, for every pair of directions ω_i and ω_o, we have that $f_r(x, \omega_i, \omega_o) = f_r(x, \omega_o, \omega_i)$.

The Transfer Equation

The transport Eq. 20 is a general equation, unrelated to a particular physical situation of interest. In this section, we try to relate the general equation to the case of radiant energy transfer, where particles are treated as photons. There are three properties of the photons that need to be incorporated into the model:

- Photons move at constant speed (in vacuum this velocity is a universal constant denoted by c).
- Each photon has an associated frequency, an internal attribute that determines its energy and affects its behavior.
- The photons trajectory is strongly influenced by the surfaces.

First, we relate the notion of phase space flow with the corresponding radiometric concept known as *radiance*. Radiance is the energy per unit area per unit of solid angle due to radiant energy passing through a projected area. This concept is similar to the one of phase space flow, lacking to relate the notion of energy by photon, which is related to its frequency:

$$E = \hbar v, \quad (52)$$

whose unit measure is in Joules (J), and $\hbar$ is the Planck constant. The relation between phase space flux and radiance L is given by:

$$L(r,\omega) = \hbar v \Phi(r,\omega) = c\hbar v n(r,\omega), \quad (53)$$

and its unit measure is in $W/m^2 \cdot sr$.

Similarly, it is necessary to relate the source function of the phase space q with an amount relative to the radiant energy. A volumetric source term is then defined by:

$$\varepsilon(r,\omega) \equiv \hbar v q(r,\omega), \quad (54)$$

and its unit measure is in $W/m^3 \cdot sr$.

The physical process of emission is a phenomenon relative to matter and then applies to the volume. Nevertheless, it is useful to think of an abstraction that allows surfaces to be emitting. We define a surface source term given by:

$$\omega_b(s,\omega) \equiv \hbar v q b(s,\omega), \quad (55)$$

and its unit measure is in $W/m^2 \cdot sr$.

The functions L, ε, and ε_b will have the same role as the related functions, with the additional being related to significant physical quantities to the transport of radiant energy. In addition, boundary conditions are also imposed, both explicit and implicit. In this way, the transport Eq. 20 can be written in terms of L:

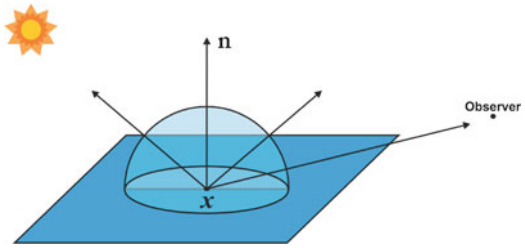
$$\begin{cases} \omega \cdot \nabla L(r,\omega) + \sigma(r)L(r,\omega) \\ = \varepsilon(r,\omega) + \int_{S^2} k(r;\omega' \cdot \omega)L(r,\omega')d\omega' \\ L(s,\omega) = \varepsilon_b(s,\omega) + \int_{H_s^-} k_b(s;\omega' \to \omega)L(s,\omega')d\omega' \end{cases} \quad (56)$$

Lighting Model

The illumination problem can be stated as follows (Gomes and Velho 2008):

Given a point $x \in S$ on a surface $S \subset \mathbb{R}^3$, a light source l and an observer at a point O,

determine the light energy L, from point x, which is perceived by the observer.



The illumination problem

We have seen that the lighting equation describes the propagation of radiant energy in space. In previous sections was presented a particle model, much used in radiative transport theory. In lighting, each particle is called a photon, which carries a certain amount of radiant energy. Illumination is the result of the movement of these photons. We defined radiant power (Φ), which is the radiant energy per unit of time.

Based on this information, if $dAd\omega$ is a volume element in phase space, the number of photons passing through dA in the neighborhood of the point x, under an infinitesimal element of solid angle $d\omega$ in direction ω, at time t, is given by:

$$\Phi(x, \omega, t) dA d\omega. \tag{57}$$

Light carries radiant energy, so we can consider the lighting equation as a problem in the area of transport theory, which studies the distribution of abstract particles in space and time. In order to obtain an expression of this equation, two hypotheses will be considered, namely, the system is in equilibrium and the medium is nonparticipative (Gomes and Velho 2008).

When the system is in equilibrium, the conditions of light propagation in the environment do not change during the simulated time interval. This condition implies that the flow is constant at all points of the scene:

$$\frac{\partial \Phi}{\partial t} = 0. \tag{58}$$

The hypothesis that the transmission occurs in a nonparticipative medium corresponds to suppose that the simulation is done in the vacuum. In this way, the only important phenomena happen on the surfaces of objects in the scene. The radiant energy transport in the vacuum between two points is given by the expression:

$$\Phi(r, \omega) = \Phi(s, \omega), \tag{59}$$

where r, s are points mutually visible in the direction ω, as illustrated in Fig. 11a.

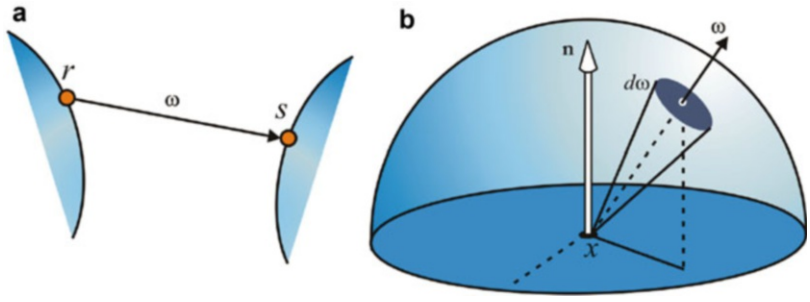
The Eq. 59 is valid for any pair of points in the surrounding space that satisfies the visibility condition. In particular, in computer graphics problems, the interest lies in the surface points of the scene. Given a point r, we find the point $s \in M$ using the *surface visibility function,* denoted by $v : \mathbb{R}^3 \times S^2 \rightarrow \mathbb{R}$, which returns the distance from the nearest visible point on a surface of the scene:

$$v(r, \omega) = inf\{\alpha > 0 : (r - \alpha\omega) \in M\}. \tag{60}$$

The point s is given by:

$$s = r - v(r, \omega)\omega. \tag{61}$$

The lighting function at a surface point x potentially depends on the flow of radiant energy coming in from all directions. In this way, the



Rendering Equation, Fig. 11 (**a**) Mutually visible points and (**b**) hemisphere of illumination

concept of *illumination hemisphere* Ω is used, which is defined by an imaginary unitary sphere whose center is at x (Gomes and Velho 2008). The luminous energy radiating from point x as well as the energy reaching the point x define a solid angle in the hemisphere. Thus, the illumination hemisphere controls all energy exchange between the surface point x and the environment around it, as illustrated by Fig. 11b.

Boundary Conditions

To formulate the illumination problem completely, it is necessary to define the boundary conditions, or what happens when light rays reach surfaces in the scene. According to Gomes and Velho (2008), there are two boundary conditions, the explicit and the implicit. In explicit condition the flow from a point s of the surface in direction ω is independent of the incident flux. This is the case with light sources. The lighting function is given by:

$$\Phi(s,\omega) = \mathcal{E}(s,\omega), \tag{62}$$

where $\mathcal{E}$ specifies the emissivity function of the surface.

In the implicit condition, the flux from a surface point s in direction ω depends on the incident flux in the illumination hemisphere. The function is given by:

$$\Phi(s,\omega) = \int_{\Omega_i} f_r(s,\omega_i,\omega_o)\Phi(s,\omega_i)d\omega_i, \tag{63}$$

where f_r is the BRDF.

The Radiance Equation

Based on everything seen in the previous sections, it is possible to state the radiance equation of a surface. In physical terms, the total radiance leaving a surface has two distinct sources: its own energy (emitted) and reflected energy:

$$\begin{aligned}\text{Total Radiance} = {} & \text{Radiance emitted} \\ & + \text{Radiance reflected.}\end{aligned} \tag{64}$$

To formulate the lighting equation, it starts with the transport equation between two points r and s:

$$\Phi(r,\omega) = \Phi(s \rightarrow, r, \ \omega), \tag{65}$$

where the notation $s \rightarrow r$ means the transport from s to r.

Border conditions need to be introduced. Thus, at each point r one wishes to obtain the contribution of radiant energy from all points s that are visible within the illumination hemisphere Ω_i in r. In this way, the right side of the Eq. 65 is replaced by the two boundary conditions (62) and (63):

$$\begin{aligned}\Phi(r,\omega_o) = {} & \mathcal{E}(s,\omega_o) \\ & + \int_{\Omega_i} f_r(s,\omega_i \rightarrow \omega_o)\Phi(s,\omega_i)d\omega_i,\end{aligned} \tag{66}$$

where s is determined by the visibility function v, given by expression (60). The transport Eq. 66 is a Fredholm integral equation of second type (Gomes and Velho 2008).

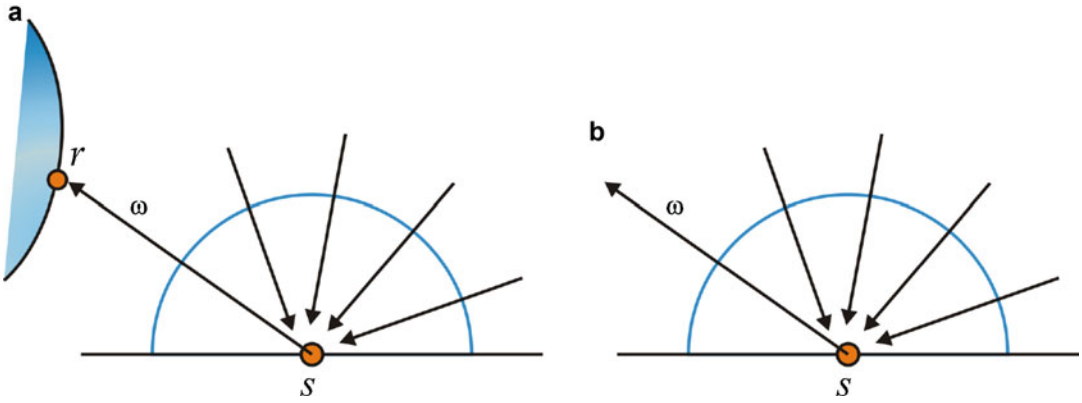
In order to obtain the total amount of radiant energy, the concepts of radiometry are used. The Eq. 33 defines the radiance magnitude L which is the radiant flux on a surface in a given direction, per unit of solid angle and per projected area. In this way, replacing this concept in the statement (64), we have that:

$$\begin{aligned}L(r,\omega_o) = {} & L_E(r,\omega_o) \\ & + \int_{\Omega_i} f_r(s,\omega_i \rightarrow \omega_o)L(s,\omega_i)cos\theta d\omega_i.\end{aligned} \tag{67}$$

The Eq. 67 is known as *radiance equation* or *rendering equation* (Kajiya 1986). The geometry is illustrated in Fig. 12a.

A modified version of the rendering Eq. 67 describes the energy radiated from a point s in direction ω in terms of the incident energy in the illumination hemisphere in s:

$$\begin{aligned}L(s,\omega_o) = {} & L_E(s,\omega_o) \\ & + \int_{\Omega_i} f_r(s,\omega_i \rightarrow \omega_o)L(s,\omega_i)cos\theta d\omega_i.\end{aligned} \tag{68}$$



Rendering Equation, Fig. 12 Geometries of rendering equation

This equation represents the total radiance of the energy coming out of a surface through the upper hemisphere. Its geometry is illustrated in Fig. 12b.

Rendering Calculation

The lighting equation, in general, must be solved numerically and approximate. To study the solution of the integral equation, the reference (Gomes and Velho 2008) proposes to use operator notations. If F is a function space, we define the integral operator $K : F \rightarrow F$, with:

$$(Kf)(x) = \int k(x, y) f(y)\, dy. \qquad (69)$$

The k function is called *core* of the operator. In this way, it is indicated that the K operator is applied in a function $f(x)$ by $(Kf)(x)$. Thus, one can write the rendering equation using the notation of operators:

$$L(r, \omega_o) = L_E(s, \omega_o) + (KL)(s, \omega_o), \qquad (70)$$

or $L = L_E + KL$.

The difficulty in solving the Eq. 70 lies in the fact that incognito function L appears on both sides of the equality. An approximate solution to the problem is the method of successive substitutions. The L function is defined recursively, so the Eq. 70 gives an expression for L. The basic idea is to substitute L for its expression on the right side of the equality, obtaining:

$$\begin{aligned} L &= L_E + K(L_E + KL) \\ &= L_E + KL_E + K^2 L \end{aligned}$$

where the exponent indicates the successive application of the operator K to a function f : $(K^2 f)(x) = (K(Kf))(x)$. Repeating the process $n + 1$ times:

$$\begin{aligned} L &= L_E + KL_E + \ldots + K^n L_E + K^{n+1} L \\ &= \sum_{i=0}^{n} K^i L_E + K^{n+1} L \end{aligned}$$

This recurrence relation provides an approximate way to calculate L. Ignoring the residual term of order $n + 1$, we have that:

$$L \approx L_n = \sum_{i=0}^{n} K^i L_E. \qquad (71)$$

The method of substitutions applied to the calculation of the lighting function has a very intuitive physical interpretation. The known term L_E corresponds to the radiant energy emitted by the light sources. The integral operator K models the propagation of reflected light on the surfaces. In this way, KL_E corresponds to the illumination of light sources which is reflected directly by the surfaces. Its successive application models the propagation of reflected light n times in the scene.

Appendix A

Mathematical Foundations

This appendix used as reference the work (Gomes and Velho 2008) and aims to highlight some important mathematical concepts for the study in question.

Spherical Coordinates

The unit sphere $S^2 \subset \mathbb{R}^3$, $S^2 = \{(x, y, z) \in \mathbb{R}^3; x^2 + y^2 + z^2 = 1\}$ has a natural parameterization, called *spherical coordinates,* which is based on the fact that each point of S^2 is characterized by the angles of longitude θ and latitude ϕ, as illustrated in Fig. 13.

From figure:

$$x = x(\theta, \phi) = cos\phi cos\theta;$$
$$y = y(\theta, \phi) = cos\phi sen\theta;$$
$$z = z(\theta, \phi) = sen\phi.$$

Solid Angle

The concept of solid angle is used in the definition of radiometric quantities by describing flows through a given region of a surface in a particular direction. To define a solid angle, one must define the concept of *spherical projection.*

Given a sphere $S^{n-1}(r)$ of radius r in $\mathbb{R}^n$ with center at the origin, the spherical projection is the transformation $p : \mathbb{R}^n - \{0\} \rightarrow S^{n-1}(r)$ defined by $p(x) = rx/|x|$. Geometrically this transformation projects the point x on the surface of the sphere along the radius that leaves the origin 0 of $\mathbb{R}^n$ and passes through x, as illustrated in Fig. 14.

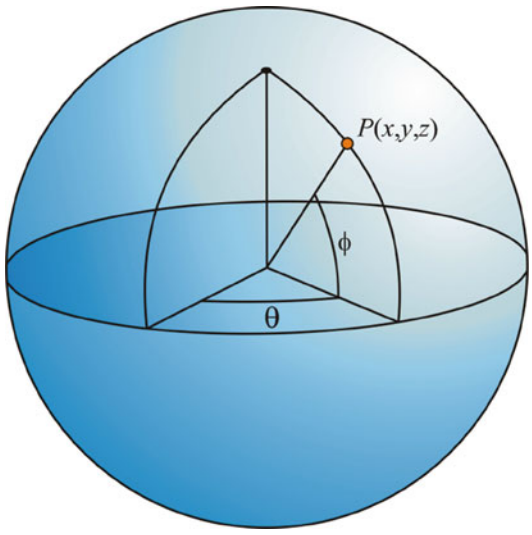
Consider a unit circle with center O. The concept of planar angle comes from the projection of an object in the circle. The measure of the arc of the circle containing the projection of the object corresponds to the planar angle.

The solid angle concept is an extension of the planar angle concept to measure the apparent area of objects in space. Consider a subset A of space, and a point O, which is the origin of observation. The measure of the solid angle ω determined by A is obtained as follows: we take a unit sphere S^2 with center in O and the spherical projection $p(A)$ of the set A on the sphere S^2. The area of $p(A)$ is the measure of ω. Figure 15a illustrates this concept.

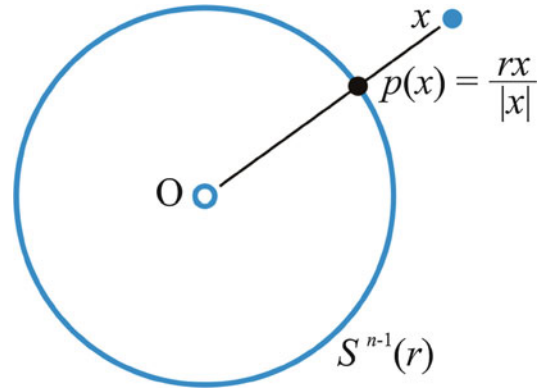
If it is necessary to take a sphere of radius r with center O, simply divide the projected area by the square of the radius. The measure of solid angle is given by:

$$\omega = \frac{\text{Area}(p(A))}{r^2}. \tag{72}$$

The spherical projection determines a cone of vertex O and base A, as illustrated in Fig. 15b.



Rendering Equation, Fig. 13 Spherical coordinates



Rendering Equation, Fig. 14 Spherical projection

This cone is the solid formed by the set of all semi-straight lines of the space originating from O and passing through points of the set A. The cone generalizes to three-dimensional space the geometric notion of the angular region of the plane geometry, and the Eq. 72 is a measure of this three-dimensional angular region.

According to Gomes and Velho (2008), both planar and solid angle are dimensionless quantities. In the first case, the arc length is divided by the radius of the circle, and in the second case an area is divided by the square of the radius length. However, the radian (*rd*) is used to indicate the measure of a planar angle and the stereo-radian (*sr*) as the unit of measure of a solid angle.

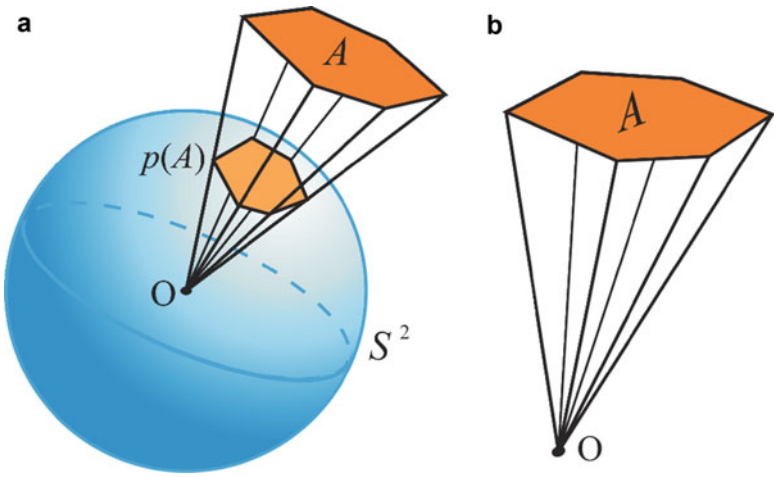
The light phenomena depend on the position of observer and therefore in general what matters is the projected area, which is the projection of the real area in the plane perpendicular to the radius of view. The projection of visualization is conical; however, if the area is very small in relation to the distance of the observer, it is possible to suppose that the projection is parallel (Fig. 16).

In this case, it is immediate to verify that the projected area is given by the product of real area A by cosine of the angle that the radius of vision does with the normal vector at the surface A:

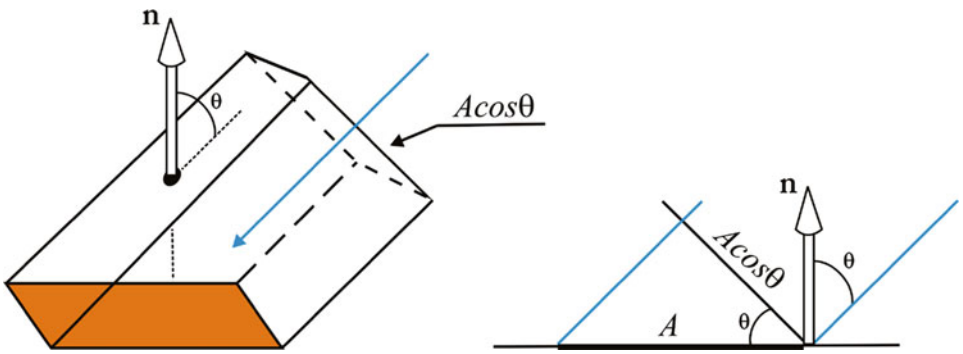
$$\text{rea projetada} = A\cos\theta. \tag{73}$$

Solid Angle Element

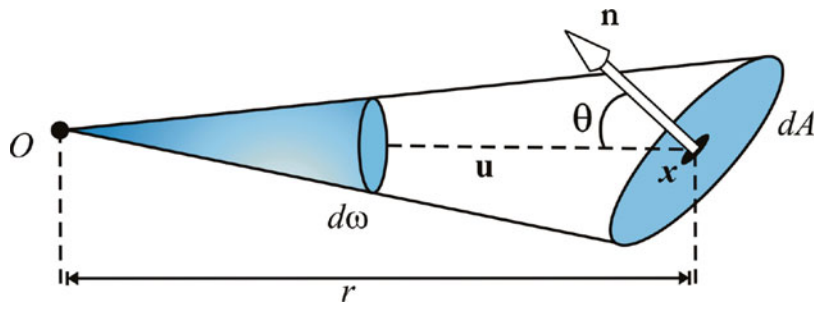
Radiometric quantities are defined by the use of rates of change of radiant energy entering or leaving a surface. In this way, it is important to define



Rendering Equation, Fig. 15 Notion of extended angle to measure the apparent area of objects



Rendering Equation, Fig. 16 Projected area



Rendering Equation, Fig. 17 Solid angle element

the infinitesimal elements of area (dA) and of solid angle ($d\omega$). Consider an area element dA of a surface A of space, and let $x \in A$ be a point of that area element at a distance r from the origin O, as illustrated in Fig. 17.

This element of area determines a solid angle element $d\omega$ from the point O in direction $\mathbf{u}$ defined by the origin O and the point x. By the definition of solid angle, the measure of $d\omega$ is given by:

$$d\omega = \frac{\text{Area}(p(dA))}{r^2}. \tag{74}$$

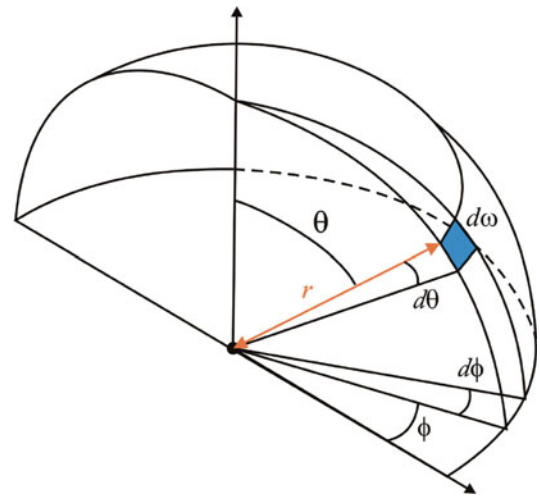
Since these are infinitesimal magnitudes, it is possible to suppose that dA is a flat surface and to replace the spherical projection by a parallel projection along direction $\mathbf{u}$. Using the Eq. 73 in the Eq. 74, we have that:

$$d\omega = \frac{dA\cos\theta}{r^2}. \tag{75}$$

The geometry of area dA can be arbitrary. In the case of a sphere, it is natural to represent the element of solid angle by a pyramid rather than a cone. Consider the sphere of radius r with spherical coordinates θ (azimuth) and ϕ (longitude) as illustrated in Fig. 18.

To determine the solid angle element at a point of spherical coordinates (ϕ, θ), one must define the area element dA of sphere. The planar angle element of a meridian passing through the point is $d\theta$, so the corresponding arc element is $rd\theta$.

The planar angle element of the equator is $d\phi$, projecting the point (ϕ, θ) in the plane of equator



Rendering Equation, Fig. 18 Solid angle element in spherical coordinates

we have that the projected radius is $rsen\theta$; therefore, the corresponding arc element is $rsen\theta d\phi$. The sphere area element dA is the product of these two arc elements:

$$dA = (rd\theta)(rsen\theta d\phi) = r^2 sen\theta d\theta d\phi. \tag{76}$$

Using Eq. 75, we obtain the measure of the infinitesimal element of the solid angle $d\omega$ in spherical coordinates:

$$d\omega = \frac{dA}{r^2} = sen\theta d\theta d\phi. \tag{77}$$

Integrating the volume element above into the whole sphere, one obtains the solid angle of the sphere:

$$\Omega = \int_0^{\pi}\int_0^{2\pi} sen\theta d\theta d\phi = 4\pi. \qquad (78)$$

Therefore, the solid angle of a hemisphere is 2π.

Cross-References

- ▶ Comic Arts in Games, Asset Production, and Rendering
- ▶ Raycasting in Virtual Reality

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Requirements Analysis

- ▶ User-Centered Design and Evaluation Methodology for Virtual Environments

Requirements Specification

- ▶ User-Centered Design and Evaluation Methodology for Virtual Environments

Resident Evil 2, History of

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Synonyms

Prerendered graphics; Survival horror; Tank controls

Definitions

Survival horror: genre of game that puts emphasis on a horror atmosphere, limited weapons, and puzzle solving.

Prerendered graphics: graphical assets that appear 3D visually but rendered in game as flat 2D planes.

Tank controls: movement style that was used often in early 3D gaming. The term comes from the up command always pushing the character forward, and the down command always pushing the character backward. The character spins counterclockwise when the left command is pressed, and vice versa with the right command, similar to how a tank moves.

History

Resident Evil 2, often abbreviated as *RE2,* was first released on January 21, 1998, in North America. It is the sequel to the 1996 game *Resident Evil*, both developed by *Capcom*. *Resident Evil 2* serves as a direct continuation of the prior entries' story, taking place only months after the original game's conclusion. However, the game has a new

setting and cast of characters. After a viral outbreak at the Spencer Mansion rendering its inhabitants zombified bioweapons, the virus has now spread to Raccoon City.

Resident Evil 2 meant to capitalize on the success of the original and expand upon it. Because of this, the sequel has much higher production values than its predecessor. Environments and character models are more detailed. Voice acting is improved, the enemies have more variety, and the story is told through (at the time) cutting edge CGI cut scenes instead of the often-mocked live action cut scenes of the first entry. It continues the practice of having two playable characters with two separate campaigns. The original game's two separate campaigns play largely similar with the exception of interacting with different characters. The sequel ups the ante by having "A" and "B" scenarios. The campaigns are noticeably different, and events that happen in "Scenario A" will affect events in "Scenario B." Since each character has an "A" and "B" scenario, this brings the number of available campaigns to four.

Gameplay

The game plays similarly to its predecessor. 3D movement is controlled using tank controls in a static prerendered environment. This allows the developers to control the camera at all times, at the cost of visibility and mobility to the player. While this allows the developers to control the scares, it is often considered archaic by today's standards. The controls are considered a point of contention in gaming with some critics underlining that they are essential for a true survival horror experience, while others pointing out the poor design and their potential to inhibit the player more than to scare. The game progresses by the player finding items to solve puzzles, dispatching enemies and occasional bosses, and opening up the map using keys found in the environment. The game follows the story of two protagonists, Leon S. Kennedy and Claire Redfield, as they are trying to escape the Raccoon City which is under a zombie infestation. During the game, their paths cross with characters related with the Umbrella Corporation that initiated the zombie outbreak through a substance called G-virus, and their survival is tied to discovering the origins of the virus. Although *Resident Evil* is not the first survival horror franchise, it is the first to coin the term (Kirkland 2009). An emphasis on limited weapons and healing items, running from enemies instead of fighting them, and item management is what defines the game's experience. The game would go on to be a critical and commercial success (Metacritic n.d.; Eriksen 2020). It solidified the series as one of *Capcom*'s most lucrative franchises and has been ported to numerous systems over the years (as well as a movie adaptation franchise with mixed success; Lay 2007; Lukas 2009).

Production

In spite of the game's success, the production was incredibly troubled. Beginning only 1 month after the original's completion, development had to be scrapped when the game was around 60–80% completed. This version of the game, nicknamed *Resident Evil 1.5*, was radically different from the final product (Hurley 2018). While similar gameplay-wise, the original prototype had original environments, characters, story, and countless other assets that were all scrapped. Maintaining the scares of the original was important to the development team. Producer/series creator Shinji Mikami was unsatisfied with the original demo of the game and would later go on to say that the gameplay and locations were "dull and boring" (Whitehead 2012).

Remake

The game is often considered to be one of the best games on the original PlayStation and the series' 20+ year history, and the best game in the series' classic era. (As of November 2020, the original game has a 89/100 critic score and 9.2/10 user score on Metacritic.com https://www.metacritic.com/game/playstation/resident-evil-2) Leon

Kennedy and Claire Redfield continue to be the most popular characters in the franchise, and the setting of Raccoon City continues to be one of the most famous locations in gaming history (Ackerman 2019). The legacy of the game would lead to a successful remake (McWhertor 2019) that Capcom released on January 25, 2019. This reimagining would go on to sell 7.2 million copies, outselling the original. Ensuring that Leon and Claire's story would continue to be told to a whole new generation of gamers.

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▶ Video Games

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Retailing

▶ Virtual Reality Retailing

Reversed Face Beautification

▶ Face Beautification in Antiage

Revival of Indigenous Languages

▶ Indigenous Language Revitalization with Stories and Games

RGB

▶ Color: Pixels, Bits, and Bytes

Rigid Body Physics

▶ Game Physics Engine, Overview

Rigor-Relevance Debate

▶ Academic and Video Game Industry "Divide"

Robot

▶ Virtual Reality and Robotics

Robot Navigation

▶ Locomotion and Human Tracking in Healthcare Robots

Rocket League: An Analysis

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Synonyms

Sports Game

Definitions

Sports Simulator Game = a game made to mimic how sports are played.

Rocket League: A Sports Simulator Game

Rocket League is a sports simulator game developed and published by Psyonix. Its ESRB rating is E for everyone. Rocket League uses the Unreal three game engine. Rocket League first came out on the PlayStation 4 in 2015, and followed by the Xbox One, PC, and the Nintendo Switch in 2016. Rocket League features crossplay between all platforms. It is a multiplayer-focused game with several game modes ranging from one player versus one player to four players versus four players that last around 5 min. The concept of Rocket League is a soccer game but with cars instead of people (Zamora 2018).

The game's concept is simple as it is similar to soccer; players compete against others players in teams while controlling a rocket-powered car. There are many varieties of cars that players can customize in design and functionality. The target audience is competitive sports lovers and racing fans of any age group. In the main game mode, players chase a ball around to score in their opponent's net. There is a game mode called "Rumble" that is a variation on the original mode, but with added power-ups that change how the game is played. There are other game modes that focus around hockey, basketball, and a variation of volleyball. Lastly, players have the option to customize aspects of the game, such as goals needed to win, the ball's speed, gravity, car movements, etc. The basic movements and mechanics of the car involve boosting, flipping and jumping, and drifting. Players can combine boosting with jumping to propel their car in any direction. Using the ability to change direction in the air allows for more advanced shots of the ball than any ground-based gameplay would allow.

Rocket League is solely multiplayer. All the maps play the same with two goals and pads around the map to pick up the nitro. There is a simple leveling system. The max level is 75, taking months' worth of gameplay to achieve. The reason behind the lengthy time to max out a level is due to the fact that the sole way to get experience is simply by playing ranked matches. The leveling system also brings with it titles: level 1–9 is rookie, 10–19 is semi-pro, 20–29 is pro, 30–39 is veteran, 40–49 is expert, 50–59 is master, 60–73 is legend, and finally 74–75 is rocketeer. It takes 10,462,750 experience to get to the max level, which is reachable at least after several weeks of playing. The interface is very simple; it is a third-person view of the vehicle in the game, along with the time limit and score in the game.

The game was well received by critics and had a large fan base at launch that has gotten smaller as the game progressed; however, their current fan base is extremely loyal. Gabriel Zamora, writing in PC Magazine, praised the action elements of the game while criticizing the game's camera and high skill curve. "To say Rocket League is exhilarating is an understatement. Shooting through the sky to make a last-minute save, vaulting over your opponent to slap the ball out of their possession, or racing up a wall to intercept an errant ball are just a few of the crazy maneuvers you can expect to see during a match of Rocket League. The beauty of

the game is that you get rewards for executing fundamentals, as well as goals scored, so you needn't compete with your teammates and hog the ball. Actions, such as assisting other players with a goal, centering the ball in front of your opponent's goal, or clearing your own goal of the ball, all earn you points, so playing defender or support is just as worthwhile as playing the attacker. In that way, Rocket League is FIFA on wheels." Ludwig Kietzman of GamesRadar admired the thrill of chasing the ball inside the arena. "The joy of Rocket League is in finding all the pre-nudge possibilities and permutations and becoming so attuned to your car's movements that explicit thinking evaporates, leaving only instinct in the eternal battle of who's gonna nudge next. You'll learn something new and minor almost every round: how much distance you can cover with the double-jump forward flip, or how high is too high for you to sail right below the ball in misguided anguish. There's the sideways flip-boost, sending the ball into the goal at a right angle; the glorious (but especially difficult) rocket flight above everyone else to snatch a ball from the heavens, the rude bump of an opponent to ruin their planned trajectory into a rocket-fuel pickup on the field. There is just as much skill to learn as there is to demonstrate by accident (don't worry, nobody will ask if it's the latter)." Kietzman critiqued the lack of a spectator mode to let other players view a match without playing and the XBOX One's version for not having an option to play with users from other consoles, although since the article was written both of these issues had been addressed (Kietzman 2016).

Psyonix had a marketing campaign that focused on getting attraction with streaming and video-sharing websites. Most of the current community started playing the game out of curiosity but stayed after they found a competitive scene. The community currently has a large following on several websites such as Youtube, Twitch, and Reddit (Needleman 2015). There is also a Rocket League eSports scene. The vice president of Psyonix contributes the success and the rise of the eSports scene to players who livestreamed the game on Twitch. "Twitch and its streamers have been an instrumental part of our success since we launched last July, and that made them a perfect match for us. We couldn't be more thrilled to be working with a team that we respect as highly as we do Twitch, and we can't wait to show the world what we can do in eSports together!" Matches are streamed live on Twitch and re-uploaded to YouTube to be viewed at later dates (Makuch 2016).

Cross-References

▶ Crowd Simulation

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Role-Playing Game

▶ Persona 3 and the Lens of Surprise
▶ The Elder Scrolls V Skyrim

Room Acoustics

▶ Sound Spatialization

Room Response Equalization

▶ Sound Spatialization

ROP-Skill System: Model in Serious Games for Universities

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Synonyms

Escape room; Game based learning; Pedagogy; Serious games; Skill system; Skill tree; Unity

Definition

The ROP-Skill System – the model was developed for Serious Games, which are used as interactive materials in universities to supplement content and as an extension for more complex problems. The model uses collected points for skilling new abilities, but if you have finished a bonus level, chosen a higher difficulty level, or used special artifacts the system switches to random for skilling.

Introduction

In the age of digitalization for higher education, medicine, or business, Serious Games are used as interesting interactive exercises. In terms of knowledge, diversity, and group dynamics, digital games allow universities to introduce complex subjects in new formats tailored to provide motivation for different educational levels. However, the development and the extension of content in Serious Games takes time, money, and staff. One possibility is the development and the usage of a Skill System for lecturers, which would change the content of skills but not the story. The ROP-Skill System – model is based on a decision tree with two different strategies: extend the learning content in a Serious Game and use the Self-Determination Theory (SDT) components for different types of motivation. In this entry, we discuss the theory, functionality, and benefits of the skill system – model for Serious Escape Games.

Educational Theory

The ROP-Skill System uses the self-determination theory (SDT) which refers to the flow experience (Chen and Hwang 2015), (Kiili et al. 2014), (Su and Hsaio 2015), and the Cognitive Evaluation Theory (CET) (Erhel and Jamet 2013), (Yang 2012). The flow theory with the flow experience concept by Csikszentmihalyi (Csikszentmihalyi 1990) and the extension of Kiili et al. (Kiili et al. 2014) with the playability shows the high potential in evaluating the quality of educational games. In this context, the flow experience can be defined as a complete state of engagement in a task, without distraction by thoughts or emotions. One argument is that students with higher self-determined motivation are more rapid to reach the flow experience and to be deeply engaged in their task (Lee 2005).

The cognitive evaluation theory (Ryan and Deci 2000) is based on different types of motivation. "The concept of intrinsic motivation (IM) refers to behaviors performed out of interest and enjoyment. In contrast, extrinsic motivation (EM) pertains to behaviors carried out to attain contingent outcomes" (Vallerand and Ratelle 2002).

In the SDT are different types of motivations relevant for a new action. In this context, Ryan and Deci found that "motivation concerns energy, direction, persistence, and equifinality – all aspects of activation and intention" (Ryan and Deci 2000b). Motivation can be separated into three categories (Table 1): amotivation, that is, a deficit of motivation, extrinsic motivation, that is, motivation for a specific external reward and intrinsic motivation, that is, motivation derived from one's own inherent interest or enjoyment (Ryan and Deci 2000; Deci and Ryan 2000).

In the educational context, the students need a certain level of competence and connection with other people (e.g., peers, teachers) to feel self-determined. The feeling of control in the learning task and their activities within the task shows that

ROP-Skill System: Model in Serious Games for Universities, Table 1 Self-determination in a context of regulation type and autonomy (Ryan and Deci 2009)

Intrinsic motivation	Extrinsic motivation				Amotivation
Intrinsic regulation	Integrated regulation	Identified regulation	Introjected regulation	External regulation	Non regulation
Highest relative autonomy	←			→	Lowest relative autonomy

the degree of autonomy corresponds with the students feeling in the classroom (Reeve 2002).

If a certain level of autonomy is allowed for students, the result shows that the students feel more competent, open-minded, and creative (Jang et al. 2010). It shows that students' perceptions of autonomy can be influenced by the "autonomy supportive" of the teacher. In the literature review by Talor et al. (Taylor et al. 2014), the SDT was extended by the Academic Motivation Scale (AMS) (Vallerand and Bissonnette 1992) and shows that a relation between STD and academic achievement is possible.

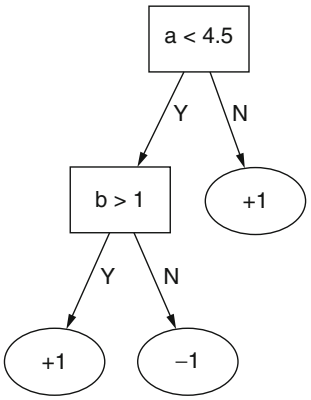
In a context where we are working to foster very specific components within the mechanics of the game (Bellotti et al. 2011), a model such as the ROP-Skill System is very helpful, because the level of autonomy is very high. The concept uses the self-determined motivation and fosters the learning in different steps.

Decision Tree

The ROP-Skill System is based on the principles of a decision tree (Fig. 1) (Freund and Mason 1999) and uses it for step by step learning. The development of the decision tree depends on the player's decisions, their chosen level of difficulty, and special items or completed bonus levels. If a player wants to reach the next skill, they need points or the activation of the "Random" mode. In the next section, we describe the ROP-Skill System – model and the rules for skilling. We analyze its impact on games in which it has been used so far.

ROP-Skill System – Model

The ROP (Random Or Points) Skill System – model (Fig. 2) uses two different strategies to unlock new skills.



ROP-Skill System: Model in Serious Games for Universities, Fig. 1 Decision tree

Points Strategy

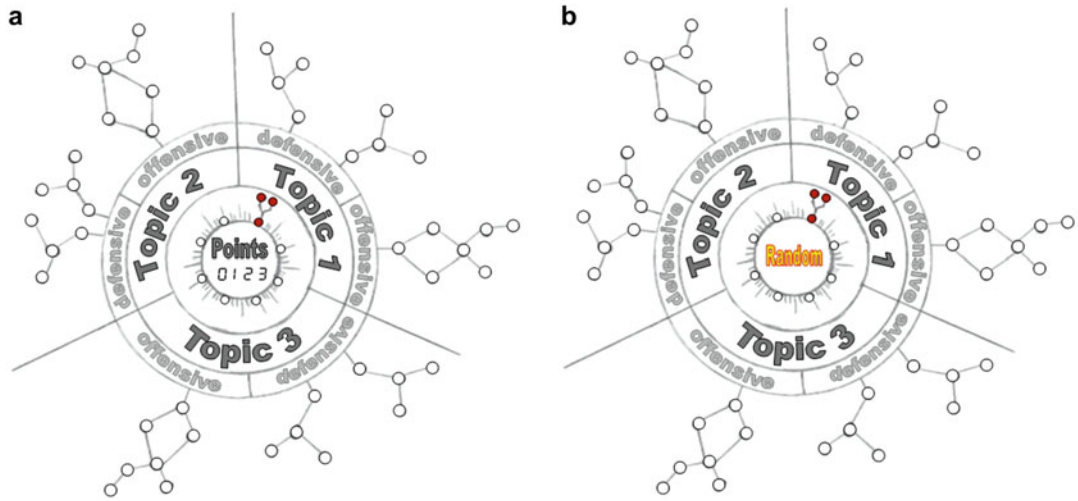
In the normal mode of the game, the player collects points, which are shown in the ball in the middle of the model, and uses them to improve their skills or equipment. In this context, the skillable options are adapted to the content of the module of the teacher. Since the model is designed for a duration of one semester, there are only a few available classes that represent the main topics of the module from the teacher's perspective. Whenever enough points are collected, a skill in a corresponding class is possible.

Random Strategy

The "random" skill mode is only activated automatically for certain events.

1. If a special item is used or it is in the player's inventory menu.
2. When a bonus level is completed.

If the random mode is active, the ball in the middle of the model changes from points to



ROP-Skill System: Model in Serious Games for Universities, Fig. 2 ROP-Skill System – Model (**a**) Using the "points strategy"; (**b**) the model switches to the Random-Mode

random and the selection pointer rotates like a wheel of fortune, which can be stopped with enter. The selection pointer comes slowly to a standstill in a class.

Once the appropriate class has been selected, the system now assigns a new skill corresponding to three modes of difficulty. This can be to the player's advantage or disadvantage.

Mode 1 (Easy): The menu pointer rotates slowly and when a class is selected by the player's strengths, that is, where the player has already assigned a skill, another skill is added. Otherwise one of the trees at level 1 is randomly skilled in an empty class.

Mode 2 (Normal): The menu pointer rotates with medium speed. After that a class is selected and randomly skilled.

Mode 3 (Hard): The menu pointer rotates quickly and when a class is selected, the player weakens, that is, only one skill point is added to the tree that has not been skilled before.

At the end of the random skill, the ball in the middle changes again from random to points. This also happens if a class is selected for the random skill that is already completed so that the random skill fails and the ball changes from random to points again.

Bonus Level

Each bonus level can be completed with each class of the corresponding level, because the bonus levels contain all elements of the corresponding classes.

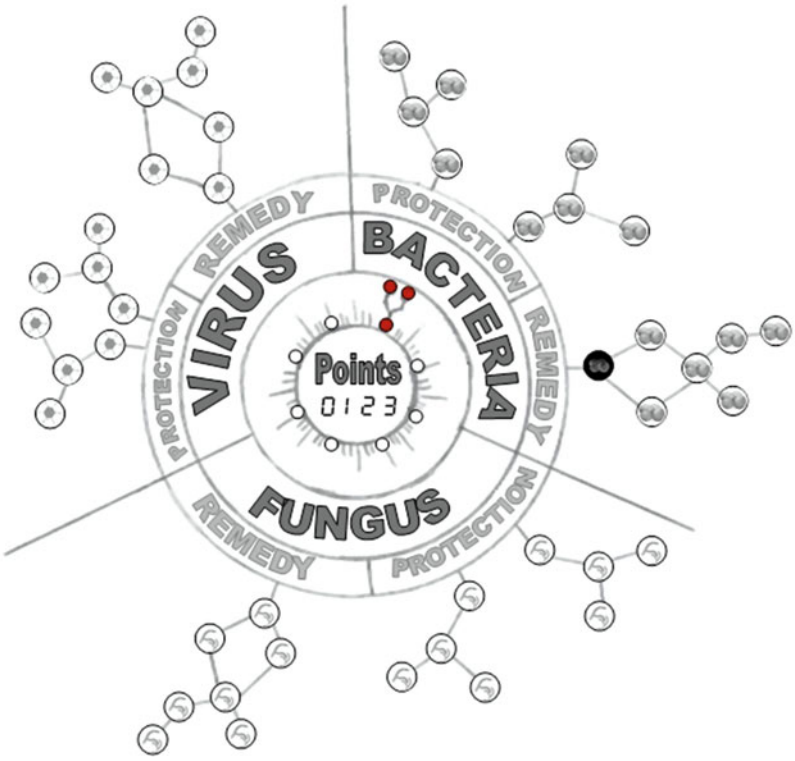
Special Items

If a particular item belonging to a class is equipped or used, more points can be collected or the probability of a random skill increases.

ROP-Skill System for a Practical Example in Biology

A practical example for using the ROP-Skill System is provided by the Serious Escape Game "Lysordion," which is currently in the conceptual phase and developed for the module "General Microbiology" for medicine, chemical engineering, and pharmaceutical biotechnology courses.

In "Lysordion," the player becomes ill with "Red Eye," a deadly plague, and is locked in a quarantined zone on a campus from which they have to escape. In 15 levels, the player solves a series of Escape Room puzzles to find a cure and protection from the plague. After each level, the player has the opportunity to improve their skills and learn new skills through the ROP-Skill System before the new escape room level starts.



ROP-Skill System: Model in Serious Games for Universities, Fig. 3 ROP-Skill system for the concept of "Lysordion"

For this module, the ROP-skill tree reduced main topics to three categories: bacteria, virus, and fungus. Each skill represents a historical experiment from the beginning to the modern era and contains instructions, which allows the player to do the experiment and to get previous knowledge.

In this example (Fig. 3), the points were used to collect new knowledge in the category "Bacteria" for the production of a remedy. The newly learned ability is marked in black. This skill introduces Griffiths' experiment on mice with *Streptococcus pneumoniae* and the instructions. The player can now carry out the experiment within the quarantined zone and try to identify the organism of "Red Eye." A special item here is, for example, the antique syringe from a showcase with which a random skill is possible in the experiment.

If the player skills in the wrong class during the game in the search for a cure for "Red Eye" and cannot find a cure, the game can still be completed with an alternative ending. Depending on the scenario, the player escapes with different outcomes.

Conclusion

The ROP-Skill System was designed for the lecturers in universities to optimize Serious Escape Games and reduce the content of one semester to a few classes. The using of two different methods for skilling makes the game more difficult, but also interesting and the modes of difficulty change the skill system to create new challenges. Special items and completed bonus levels are also rewarded by the system with a random skill and motivate to continue playing. In the educational context, the ROP-Skill System shows significant advantages to expand the content of Serious Games and represents a particularly promising field of research and development.

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▶ Serious Online Games for Engaged Learning Through Flow

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Route Planning

▶ Locomotion and Human Tracking in Healthcare Robots

Routing

▶ Speedrunning in Video Games

Royal

▶ Fortnite: A Brief History

RPG

▶ Among Us and Its Popularity During COVID-19 Pandemic

RPG Role-Playing Game

▶ Genetic Algorithm (GA)-Based NPC Making

RTS AI Problems and Techniques

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Synonyms

Artificial intelligence; Game AI; Real-time strategy games; RTS games

Definition

Real-time strategy (RTS) games is a subgenre of strategy games where players need to build an economy (gathering resources and building a base) and military power (training units and researching technologies) in order to defeat their opponents (destroying their army and base). Artificial intelligence problems related to RTS games deal with the behavior of an artificial player. This consists among others to learn how to play, to have an understanding about the game and its environment, and to predict and infer game situations from a context and sparse information.

Introduction

The field of real-time strategy (RTS) game artificial intelligence (AI) has advanced significantly in the past few years, partially thanks to competitions such as the "ORTS RTS Game AI Competition" (held from 2006 to 2009), the "AIIDE StarCraft AI Competition" (held since 2010), and the "CIG StarCraft RTS AI Competition" (held since 2011). Based on the work presented in Othman et al. (2012), here we first define RTS games, then list the open problems in creating AI for RTS games, and finally point to the approaches that have been proposed to address these problems.

Real-Time Strategy Games

From a theoretical point of view, the main differences between RTS games and traditional board games such as Chess are:

- RTS games are *simultaneous move* games, where more than one player can issue actions at the same time.
- Actions in RTS games are *durative*, i.e., actions are not instantaneous, but take some amount of time to complete.
- RTS games are "real time," which actually means that each player has a very small amount of time to decide the next move and that, in contrast to *turn-based* games, the game keeps advancing even if a player does not execute any actions. Compared to Chess, where players may have several minutes to decide the next action, in StarCraft, a popular RTS game, the game executes at 24 frames per second, which means that players can act as fast as every 42 ms, before the game state changes.
- Most RTS games are partially observable: players can only see the part of the map that has been explored. This is referred to as the *fog of war*.
- Most RTS games are nondeterministic: some actions have a chance of success, and the amount of damage dealt by different units is sometimes stochastic.
- And, finally, the complexity of these games, both in terms of state space size and in terms of number of actions available at each decision cycle, is very large. For example, the state space of Chess is typically estimated to be around 10^{50}, heads up no-limit Texas holdem

poker around 10^{80}, and Go around 10^{170}. In comparison, the state space of StarCraft in a typical map is estimated to be many orders of magnitude larger than any of those, as discussed in the next section.

For those reasons, standard techniques used for playing classic board games, such as game tree search, cannot be directly applied to solve RTS games without the definition of some level of abstraction or some other simplification. Interestingly enough, humans seem to be able to deal with the complexity of RTS games and are still vastly superior to computers in these types of games (Buro and Churchill 2012). For those reasons, a large spectrum of techniques have been attempted to deal with this domain, as we will describe below.

In the past few years, *StarCraft: Brood War* (an immensely popular RTS game released in 1998 by Blizzard Entertainment) has become the standard testbed for evaluating AI techniques in RTS games. StarCraft is set in a science-fiction-based universe where the player must choose one of the three races: Terran, Protoss, or Zerg. In order to win a StarCraft game, players must first gather resources (minerals and Vespene gas). As resources become available, players need to allocate them for creating more buildings (which reinforce the economy and allow players to create units or unlock stronger units), research new technologies (in order to use new unit abilities or improve the units), and train attack units. Units must be distributed to accomplish different tasks such as reconnaissance, defense, and attack. While performing all of those tasks, players also need to strategically understand the geometry of the map at hand, in order to decide where to place new buildings (concentrate in a single area or expand to different areas) or where to set defensive outposts. Finally, when offensive units of two players meet, each player must quickly maneuver each of the units in order to fight a battle, which requires quick and reactive control of each of the units.

From a theoretical point of view, the state space of a StarCraft game for a given map is enormous. For example, consider a typical 128 × 128 map. At any given moment, there might be between 50 and 400 units in the map, each of which might have a complex internal state (remaining energy and hit points, action being executed, etc.). This quickly leads to an immense number of possible states (way beyond the size of smaller games, such as Chess or Go). For example, just considering the location of each unit (with 128 × 128 possible positions per unit), and 400 units, gives us an initial number of $16384^{400} \approx 10^{1685}$. If we add the other factors playing a role in the game, such as resources, hit points, energy, research status, cool-down timers, etc., we obtain even larger numbers (see Othman et al. (2012) for a more in-depth description of the complexity of StarCraft).

Challenges in RTS Game AI

Early research in AI for RTS games (Buro 2003) identified the following six challenges: resource management, decision making under uncertainty, spatial and temporal reasoning, collaboration (between multiple AIs), opponent modeling and learning, and adversarial real-time planning. While there has been a significant work in many, others have been untouched (e.g., collaboration). Moreover, recent research in this area has identified several additional research challenges, such as how to exploit the massive amounts of existing domain knowledge (strategies, build orders, replays, and so on). Thus, the challenges in RTS game AI can be grouped in six main different areas, described below.

Planning As mentioned above, the size of the state space in RTS games is much larger than that of traditional board games such as Chess or Go. Additionally, the number of actions that can be executed at a given instant of time is also much larger. Thus, standard adversarial planning approaches, such as game tree search, are not directly applicable. As we elaborate later, planning in RTS games can be seen as having multiple levels of abstraction: at a higher level, players need long-term planning capabilities, in order to

develop a strong economy in the game; at a low level, individual units need to be moved in coordination to fight battles taking into account the terrain and the opponent. Techniques that can address these large planning problems by either sampling or hierarchical decomposition do not yet exist.

Learning Given the difficulties in playing by directly using adversarial planning techniques, many research groups have turned attention to learning techniques. We can distinguish three types of learning problems in RTS games:

- *Prior learning*: How can we exploit available data, such as existing replays, or information about specific maps for learning appropriate strategies before hand? A significant amount of work has gone in this direction.
- *In-game learning*: How can bots deploy online learning techniques that allow them to improve their game play while playing a game? These techniques might include reinforcement learning techniques, but also opponent modeling. The main problem again is the fact that the state space is too large and the fact that RTS games are partially observable.
- *Inter-game learning*: What can be learned from one game that can be used to increase the chances of victory in the next game? Some work has used simple game-theoretical solutions to select among a pool of predefined strategies, but the general problem remains unsolved.

Uncertainty Adversarial planning under uncertainty in domains of the size of RTS games is still an unsolved challenge. In RTS games, there are two main kinds of uncertainty. First, the game is partially observable, and players cannot observe the whole game map (like in Chess) but need to scout in order to see what the opponent is doing. This type of uncertainty can be lowered by good scouting and knowledge representation (to infer what is possible given what has been seen). However, scouting also means deliberately reducing economic progress in order to obtain information. Second, there is also uncertainty arising from the fact that the games are adversarial, and a player cannot predict the actions that the opponent (s) will execute. For this type of uncertainty, the AI, as the human player, can only build a sensible model of what the opponent is likely to do.

Spatial and Temporal Reasoning Spatial reasoning is related to each aspect of terrain exploitation. It is involved in tasks such as building placement or base expansion. In the former, the player needs to carefully consider building positioning into its own bases to both protect them by creating defenses or walls against invasions and to avoid bad configurations where large units could be stuck. In base expansion, the player has to choose good available locations to build a new base, regarding its own position and opponent's bases. Finally, spatial reasoning is key to tactical reasoning: players need to decide where to place units for battle, favoring, for instance, engagements when the opponent's units are lead into a bottleneck.

Analogously, temporal reasoning is key in tactical or strategic reasoning. For example, timing attacks and retreats to gain an advantage. At a higher strategic level, players need to reason about when to perform long-term impact economic actions such as upgrades, building construction, strategy switching, etc. all taking into account that the effects of these actions are not immediate but longer term.

Domain Knowledge Exploitation In traditional board games such as Chess, researchers have exploited the large amounts of existing domain knowledge to create good evaluation functions to be used by alpha-beta search algorithms, extensive opening books, or end-game tables. In the case of RTS games, it is still unclear how the significantly large amount of domain knowledge (in the forms or strategy guides, replays, etc.) can be exploited. Most work in this area has focused on two main directions: (1) hard-coding existing strategies into bots (so that bots only need to decide which strategies to deploy, instead of having to solve the complete planning problem) and (2) mining large datasets of replays (Synnaeve et al. 2012a; Weber and Mateas 2009) to automatically extract strategies, trends, or plans.

Task Decomposition Most existing approaches to play RTS games work by decomposing the problem into a collection of smaller problems to be solved independently. Specifically, a common subdivision is:

- *Strategy*: corresponds to the high-level decision-making process. This is the highest level of abstraction for the game comprehension. Finding an efficient strategy or counterstrategy against a given opponent is key in RTS games and concerns the whole set of units a player owns.
- *Tactics*: are the implementation of the current strategy. It implies army and building positioning, movements, timing, and so on. Tactics concerns a group of units.
- *Reactive control*: is the implementation of tactics. This consists in moving, targeting, firing, fleeing, and hit-and-run techniques (also known as "kiting") during battle. Reactive control focuses on a specific unit.
- *Terrain analysis*: consists in the analysis of regions composing the map: choke points, minerals and gas emplacements, low and high walkable grounds, islands, etc.
- *Intelligence gathering*: corresponds to information collected about the opponent. Because of the fog of war, players must regularly send scouts to localize and spy enemy bases.

In comparison, when humans play StarCraft, they typically divide their decision making in a very different way. The StarCraft community typically talks about two tasks:

- *Micro*: is the ability to control units individually (roughly corresponding to *reactive control* above and part of *tactics*). A good *micro* player usually keeps their units alive over a longer period of time.
- *Macro*: is the ability to produce units and to expand at the appropriate times to keep your production of units flowing (roughly corresponding to everything but *reactive control* and part of *tactics* above). A good *macro* player usually has the larger army.

The reader can find a good presentation of task decomposition RTS game AI in Weber et al. (2011a). Although the previous task decomposition is common, other task decompositions have been explored (see Othman et al. (2012) for an overview of the task decomposition used by several StarCraft bots).

Existing Work on RTS Game AI

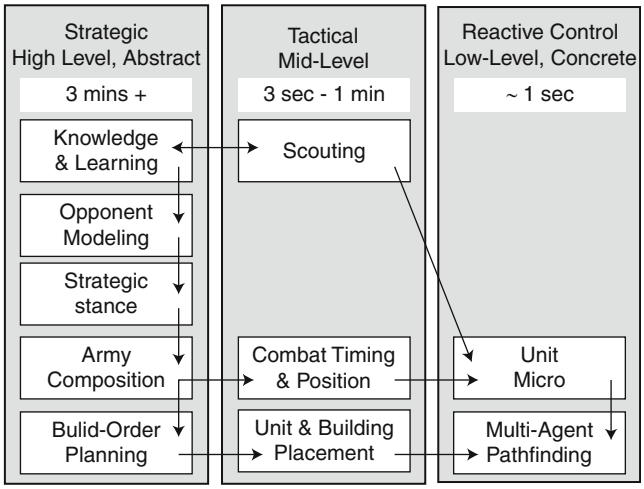
Systems that play RTS games need to address most, if not all, the aforementioned problems together. Therefore, it is hard to classify existing work on RTS AI as addressing the different problems above. For that reason, we will divide it according to three levels of abstraction: strategy (which loosely corresponds to "macro"), tactics, and reactive control (which loosely corresponds to "micro").

Figure 1 illustrates how strategy, tactics, and reactive control are three points in a continuum scale where strategy corresponds to decision-making processes that affect long spans of time (several minutes in the case of StarCraft), reactive control corresponds to low-level second-by-second decisions, and tactics sit in the middle. Also, strategic decisions reason about the whole game at once, whereas tactical or reactive control decisions are localized and affect only specific groups of units. Typically, strategic decisions constrain future tactical decisions, which in turn condition reactive control. Moreover, information gathered while performing reactive control can cause reconsideration of the tactics being employed, which could trigger further strategic reasoning.

The remainder of this section presents work toward addressing the previous six open RTS game AI problems, grouped as work focused toward strategy, tactics, or reactive control, as well as a final section dedicated to holistic approaches that attempt to deal with all three levels at once.

Strategy

In the context of RTS games, high-level strategic reasoning has been addressed using many AI



RTS AI Problems and Techniques, Fig. 1 RTS AI levels of abstraction and typical subproblems associated with them: Timings correspond to an estimate of the duration of a behavior switch in StarCraft

techniques, like hard-coded approaches, planning, or machine learning. We cover each of these approaches in turn.

Hard-Coded Approaches They have been extensively used in commercial RTS games. The most common ones use finite state machines (FSM) (Houlette and Fu 2003) in order to let the AI author hard-code the strategy that the AI will employ. The idea behind FSMs is to decompose the AI behavior into easily manageable states, such as "attacking," "gathering resources," or "repairing," and establish the conditions that trigger transitions between them. Commercial approaches also include hierarchical FSMs, in which FSMs are composed hierarchically. These hard-coded approaches have achieved a significant amount of success and have also been used in many academic RTS AI research systems. However, these hard-coded approaches struggle to encode dynamic, adaptive behaviors and are easily exploitable by adaptive opponents.

Planning Approaches using planning techniques have also been explored in the literature. For example, Ontañón et al. (2008) explored the use of real-time case-based planning (CBP) in the domain of Wargus (a Warcraft II clone). In their work, they used human demonstration to learn plans, which are then composed at run-time in order to form full-fledged strategies to play the game. In Mishra et al. (2008), they improve over their previous CBP approach by using situation assessment for improving the quality and speed of plan retrieval. Hierarchical task network (HTN) planning has also been explored with some success in the context of simpler first-person shooter games (Hoang et al. 2005). Planning approaches offer more adaptivity of the AI strategy compared to hard-coded approaches. However, the real-time constraints of RTS games limit the planning approaches that can be applied, HTN and case-based planning being the only ones explored so far. Moreover, none of these approaches address any timing or scheduling issues, which are key in RTS games. One notable exception is the work of Churchill and Buro (2011), who used planning in order to construct its economic build orders, taking into account timing constraints of the different actions.

Machine Learning Concerning machine learning-based approaches, Weber and Mateas (2009) proposed a data mining approach to strategy prediction and performed supervised learning on labeled StarCraft replays. Dereszynski et al. (2011) used hidden Markov models (HMM) to learn the transition probabilities of sequences of building construction orders and kept the most probable ones to produce probabilistic behavior models (in StarCraft). Synnaeve and Bessiére (2011a) used the dataset of Weber and Mateas (2009) and presented a Bayesian semi-supervised model to

learn from replays and predict openings (early game strategies) from StarCraft replays. The openings are labeled by EM clustering considering appropriate features. Then, in Synnaeve and Bessiére (2011b), they presented an unsupervised learning Bayesian model for tech-tree prediction, still using replays. Finally, evolutionary approaches to determine priorities of high-level tasks were explored by Young and Hawes in their QUORUM system (Young and Hawes 2012), showing improvement over static priorities.

Case-Based Reasoning Also falling into the machine learning category, a significant group of researchers has explored case-based reasoning (CBR) (Aamodt and Plaza 1994) approaches for strategic decision making. For example, Aha et al. (2005) used CBR to perform dynamic plan retrieval in the Wargus domain. Hsieh and Sun (2008) based their work on Aha et al.'s CBR model (Aha et al. 2005) and used StarCraft replays to construct states and building sequences ("build orders"). Schadd et al. (2007) applied a CBR approach to opponent modeling through hierarchically structured models of the opponent behavior, and they applied their work to the Spring RTS game (a "Total Annihilation" clone). Jaidee et al. (2011) study the use of CBR for automatic goal selection while playing an RTS game. These goals will then determine which Q-tables to be used in a reinforcement learning framework. Finally, Čertický et al. (2013) used CBR to build their army, based on the opponent's army composition, and they pointed out on the importance of proper scouting for better results.

Scouting One final consideration concerning strategy is that RTS games are typically partially observable. Games like StarCraft implement the "fog of war" idea, which basically means that a player can only see the areas of the map close to her own units. Areas of the map away from the field of view of individual units are not observable. Players need to scout in order to obtain information about the opponent's strategy. The size of the state space in StarCraft prevents solutions based on POMDPs from being directly applicable, and very few of the previous approaches deal with this problem. Much work in RTS game AI assumes perfect information all the time. For example, in the case of commercial games, most AI implementations cheat, since the AI can see the complete game map at all times, while the human player does not. In order to make the human player believe the AI of these games does not cheat, sometimes they simulate some scouting tasks as Bob Fitch described in his AIIDE 2011 keynote for the WarCraft and StarCraft game series. Even if the StarCraft AI competition enforces fog of war, which means that bots are forced to work under partial information, little published research exists on this topic. A notable exception is the work of Weber et al. (2011b), who used a particle model with a linear trajectory update to track opponent units under fog of war in StarCraft. They also produced tactical goals through reactive planning and goal-driven autonomy (Weber et al. 2010a, b), finding the more relevant goal(s) to spawn in unforeseen situations.

Tactics

We will divide the work on midrange tactical reasoning in RTS games in two large groups: spatial reasoning and decision making (that has been addressed both using machine learning and game tree search).

Spatial Reasoning The most common form of spatial reasoning in the literature of RTS games is terrain analysis. Terrain analysis supplies the AI with structured information about the map. This analysis is usually performed off-line, in order to save CPU time during the game. For example, Pottinger (2000) described the *BANG* engine implemented by Ensemble Studios for the game Age of Empires II. This engine provides terrain analysis functionalities to the game using influence maps and areas with connectivity information. Forbus et al. (2002) showed the importance to have qualitative spatial information for war games, for which they used geometric and path-finding analysis. Hale et al. (2008) presented a 2D geometric navigation mesh generation method from expanding convex regions from seeds. Finally, Perkins (2010) applied Voronoi decomposition (then pruning) to detect regions and

relevant choke points in RTS maps. This approach is implemented for StarCraft in the BWTA (http://eode.google.com/p/bwta/) library, used by most state of the art StarCraft bots.

Another form of spatial reasoning that has been studied in RTS games is *walling*. Walling is the act of intentionally placing buildings at the entrance of your base to block the path and to prevent the opponent's units from getting inside. This technique is used by human StarCraft players to survive early aggression and earn time to train more units. Čertický addressed this constraint satisfaction problem using answer set programming (ASP) (Čertický 2013). Richoux et al. (2014) presented an alternative approach based on constraint programming and local search, designed to be run-time.

Machine Learning Concerning tactical decision making, many different approaches have been explored such as machine learning or game tree search. Hladky and Bulitko (2008) benchmarked hidden semi-Markov models (HSMM) and particle filters for unit tracking. Although they used first-person shooter (FPS) games for their experimentation, the results apply to RTS games as well. They showed that the accuracy of occupancy maps was improved using movement models (learned from the player behavior) in HSMM. Kabanza et al. (2010) improve the probabilistic hostile agent task tracker (PHATT (Geib and Goldman 2009), a simulated HMM for plan recognition) by encoding strategies as HTN, used for plan and intent recognition to find tactical opportunities. Sharma et al. (2007) combined CBR and reinforcement learning to enable reuse of tactical plan components. Cadena and Garrido (2011) used fuzzy CBR (fuzzy case matching) for strategic and tactical planning. Synnaeve and Bessière (2012b) combined space abstraction into regions from Perkins (2010) and tactical decision making by assigning scores (economical, defenses, etc.) to regions and looking for their correspondences to tactical moves (attacks) in pro-gamer replays. Finally, Miles and Louis (2006) created the idea of *IMTrees*, a tree where each leaf node is an influence map, and each intermediate node is a combination operation (sum, multiplication); Miles used evolutionary algorithms to learn IMTrees for each strategic decision in the game involving spatial reasoning by combining a set of basic influence maps.

Game Tree Search These techniques have also been explored for tactical decision making. Churchill et al. (2012a) presented the ABCD algorithm (Alpha-Beta Considering Durations), a game tree search algorithm for tactical battles in RTS games. Chung et al. (2005) applied Monte Carlo planning to a capture-the-flag version of Open RTS. Balla and Fern (2009) applied the UCT algorithm (a Monte Carlo Tree Search algorithm) to tactical assault planning in Wargus. To make game tree search applicable at this level, abstract game state representations are used in order to reduce the complexity. Uriarte and Ontañón (2014) explored different game state abstractions in the context of Monte Carlo Tree Search for high-level tactical reasoning in StarCraft. Other algorithms, such as Greedy Portfolio Search (Churchill et al. 2012a), perform abstraction at the level of actions, by employing a collection of predefined "scripts" and using these scripts as the possible actions that the players can execute in the context of game tree search.

Reactive Control

Reactive control has been addressed mainly via the application of potential fields or by using machine learning to learn good control policies. We also include work on pathfinding as part of reactive control.

Potential Fields Potential fields and influence maps have been found to be useful techniques for reactive decision making. Some uses of potential fields in RTS games are avoiding obstacles (navigation), avoiding opponent fire (Uriarte and Ontañón 2012), or staying at maximum shooting distance (Hagelbäck and Johansson 2009). Potential fields have also been combined with A* pathfinding to avoid local traps (Hagelbäck 2012). Hagelbäck and Johansson (2008) presented a multi-agent potential field-based bot able to deal with fog of war in the Tankbattle game. Avery et al. (2009) and Smith et al. (2010) coevolved

influence map trees for spatial reasoning in RTS games. Danielsiek et al. (2008) used influence maps to achieve intelligent squad movement to flank the opponent in an RTS game. Despite their success, a drawback for potential field-based techniques is the large number of parameters that has to be tuned in order to achieve the desired behavior. Approaches for automatically learning such parameters have been explored, for example, using reinforcement learning (Liu and Li 2008) or self-organizing maps (SOM) (Preuss et al. 2010). We would like to note that potential fields are a reactive control technique, and, as such, they do not perform any form of lookahead. As a consequence, these techniques are prone to make units stuck in local optima.

Machine Learning There has been a significant amount of work on using machine learning techniques for the problem of reactive control. Bayesian modeling has been applied to inverse fusion of the sensory inputs of the units (Synnaeve and Bessiere 2011c), which subsumes potential fields, allowing for integration of tactical goals directly in micromanagement.

Additionally, there have been some interesting uses of reinforcement learning (RL) (Sutton and Barto 1998): Wender and Watson (2012) evaluated the different major RL algorithms for (decentralized) micromanagement, which perform all equally. Marthi et al. (2005) employ concurrent hierarchical Q-learning (units' Q-functions are combined at the group level) RL to efficiently control units in a "one robot with multiple effectors" fashion. Madeira et al. (2006) advocate the use of prior domain knowledge to allow faster RL learning and applied their work on a turn-based strategy game. This is because the action space to explore is gigantic for real game setups. It requires exploiting the existing structure of the game in a partial program (or a partial Markov decision process) and a shape function (or a heuristic) (Marthi et al. 2005). Another approach has been proposed by Jaide and Muñoz-Avila (2012) through learning just one Q-function for each unit type, in order to cut down the search space. Other approaches that aim at learning the parameters of an underlying model have also been explored. For example, Ponsen and Spronck (2004) used evolutionary learning techniques, but face the same problem of dimensionality. For example, evolutionary optimization by simulating fights can easily be adapted to any parameter-dependent micromanagement control model, as shown by Othman et al. (2012) which optimizes an AIIDE 2010 micromanagement competition bot.

Finally, approaches based on game tree search are recently being explored for micromanagement. Churchill et al. (2012b) presented a variant of alpha-beta search capable of dealing with simultaneous moves and durative actions, which could handle reactive control for situations with up to eight versus eight units.

Other research falling into reactive control has been performed in the field of cognitive science, where Wintermute et al. (2007) have explored humanlike attention models (with units grouping and vision of a unique screen location) for reactive control.

Pathfinding Finally, although pathfinding does not fall under our previous definition of reactive control, we include it in this section, since it is typically performed as a low-level service, not part of either tactical or strategical reasoning (although there are some exceptions, like the tactical pathfinding of Danielsiek et al. (2008)). The most common pathfinding algorithm is A*, but its big problem is CPU time and memory consumption, hard to satisfy in a complex, dynamic, real-time environment with large numbers of units. Even if specialized algorithms, such as D*-Lite (Koenig and Likhachev 2002) exist, it is most common to use A* combined with a map simplification technique that generates a simpler navigation graph to be used for pathfinding. An example of such technique is Triangulation Reduction A* that computes polygonal triangulations on a grid-based map (Demyen and Buro et al. 2006). Considering movement for groups of units, rather than individual units, techniques such as steering of flocking behaviors (Reynolds 1999) can be used on top of a pathfinding algorithm in order to make whole groups of units follow a given path. In recent commercial RTS games like StarCraft 2 or Supreme Commander 2, flocking-like behaviors are inspired of

continuum crowds ("flow field") (Treuille et al. 2006). A comprehensive review about (grid-based) pathfinding was recently done by Sturtevant (2012).

Holistic Approaches

Finally, holistic approaches to address RTS AI attempt to address the whole problem using a single unified method. To the best of our knowledge, with a few exceptions, such as the Darmok system (Ontañón et al. 2010) (which uses a combination of case-based reasoning and learning from demonstration) or ALisp (Marthi et al. 2005), there has not been much work in this direction. The main reason is that the complexity of RTS games is too large, and approaches that decompose the problem into smaller, separate problems achieve better results in practice. However, holistic approaches, based, for example, on Monte Carlo Tree Search, have only been explored in the context of smaller-scale RTS games (Ontañón 2013). Techniques that scale up to large RTS games as StarCraft are still not available.

A related problem is that of integrating reasoning at multiple levels of abstraction. Molineaux et al. (2008) showed that the difficulty of working with multi-scale goals and plans can be handled directly by case-based reasoning (CBR), via an integrated RL/CBR algorithm using continuous models. Reactive planning (Weber et al. 2010b), a decompositional planning similar to hierarchical task networks (Hoang et al. 2005), allows for plans to be changed at different granularity levels and so for multi-scale (hierarchical) goal integration of low-level control. Synnaeve and Bessière (2011c) achieve hierarchical goal (coming from tactical decisions) integration through the addition of another sensory input corresponding to the goal's objective.

Conclusions

This entry has defined real-time strategy (RTS) games from an AI point of view and summarized the set of open problems in RTS game AI. After that, we have summarized existing work toward addressing those problems.

RTS games can be seen as a simulation of real complex dynamic environments, in a finite and smaller world, but still complex enough to study a series of key interesting problems. Finding efficient techniques for tackling these problems on RTS games can thus benefit other AI disciplines and application domains and also have concrete and direct applications in the ever-growing industry of video games.

Cross-References

- ▶ Computer Go
- ▶ Monte-Carlo Tree Search
- ▶ StarCraft Bots and Competitions

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RTS Games

▶ RTS AI Problems and Techniques
▶ StarCraft Bots and Competitions

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S&R

► Skull and Roses Card Game

Scalable Techniques

► Scalable Techniques to Visualize Spatiotemporal Data

Scalable Techniques to Visualize Spatiotemporal Data

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Synonyms

Information visualization; Scalable techniques; Spatiotemporal data

Definition

Spatiotemporal visualization uses a set of tools and techniques to explore and explain changes of information in space and time, aiming to convey specific insights in large and complex data sets to humans (Zhong et al. 2012).

Introduction

Our world is saturated with spatiotemporal data. Spatiotemporal visualization plays an important role in the discovery and understanding of the inherent nature of data. Zhong et al. (2012) defined spatiotemporal visualization as a set of tools and techniques to explore changes of information in space and time, aiming to convey specific insights in large and complex data sets to humans. Researchers have created numerous applications and techniques to visualize spatiotemporal data as efficiently and effectively as possible. Space-time cube (Gatalsky et al. 2004), small multiples (Tufte 2001), the choropleth map (Nöllenburg 2007), and stacked area charts (Hao et al. 2005) were proposed to represent spatiotemporal phenomena. The scalability in information visualization has been a big challenge to visualize large-scale spatiotemporal data sets. Cook and Thomas (2005) listed five major scale issues that were related to visual analytics: information scalability, visual scalability, display scalability, human scalability, and software scalability. This entry will summarize the techniques that were used to visualize spatiotemporal data from the five perspectives.

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A case study will be demonstrated with 2014 VAST Mini-challenge 2 dataset. Researchers designed a polygon-based visualization to display large GPS tracking data at different levels of time series.

State-of-the-Art Work

Information Scalability

Cook and Thomas (2005) defined information scalability as the capability to extract relevant information from massive data streams, the capability to handle dynamic change, and the capability to be scaled to the target audience.

One of information scalability tasks is to filter the data and show only the most relevant data (Robertson et al. 2009). Information scalability requires the representations of data at multiple levels of abstraction and scales. Data abstraction is able to reduce the number of items to display in data space. It attempts to hide away details without losing the essential meaning. The standard data abstraction technique is dimension reduction, whose strategies include principal component analysis, factor analysis, multidimensional scaling, subsetting, segmentation, and aggregation.

Information scalability also needs to deal with a wide range of dynamic change. The common approach is the autoregressive integrated moving average (ARIMA) methodology (Box et al. 2008). The model examines the relationships of variables over time and helps to understand the events and predict future points in the series. More recent research has focused on mining multivariate time series data. Minnen et al. (2007) proposed an algorithm to locate regions of high density in the space of all time-series subsequences to discover multivariate motifs. Wang and Willett (2004) presented a computationally efficient solution to solve the joint segmentation and classification of a time series. Some work has investigated the design of system architecture. Lian et al. (2008) proposed the pattern-matching problem over high dimensional cloaked series. The researchers indexed the cloaked time series and proposed an efficient approach to answering the cloaked range query. Besides that, distributed data streams Bandyopadhyay et al. (2006) were presented to deal with high-dimensionality streaming data. The key to the technique was the online micro-clusters that could be extracted over the required period.

Visual Scalability

Visual Scalability is the capability of visualization representation and visualization tools to display massive datasets effectively, regarding either the number or the dimension of the individual data element (Eick and Karr 2002). According to Cook and Thomas (2005), factors affecting visual scalability include the quality of visual displays, the visual metaphors used in the display of information, the techniques used to interact with the visual representations, and the perception capabilities of the human cognitive system.

A screen contains millions of pixels. Researchers cannot use all the pixels to display data elements because it is impossible for the audience to perceive them. Thus, the number of perceivable pixels and data elements that can be displayed is limited. Robertson et al. (2009) proposed that the fundamental problem of visual scalability was how to visually represent a very large number of data elements in a much smaller number of visual display elements so that the user's task could be performed. Visual scalability aims to handle huge amounts of data and display the large-scale relationship with an overview. Researchers have explored innovative ways of displaying large-scale spatiotemporal data. The approaches can be classified as geometric projections, pixel-oriented views, and hierarchical presentations.

Geometric Projections

This technique aims at finding informative projections and transformations of multidimensional datasets (Keim and Kriegel 1996). Analytics can map the attributes to a Cartesian plane like scatterplot or an arbitrary space like parallel coordinates. Tominski et al. (2012) introduced a novel stacking-based technique to facilitate gaining insights into trajectory attribute data. With a combination of 2D map and stacked 3D trajectory bands, the approach was able to display more

than 10 billion position records and 14,000 trajectories in total. To mitigate the clutter issue, recent researchers have proposed density-based approaches to visualize a lot of data points.

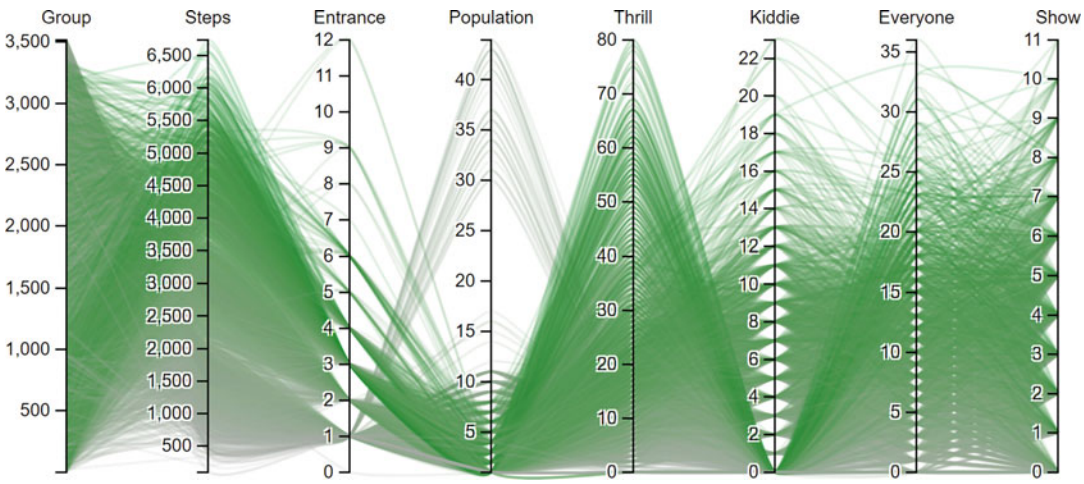
Wei et al. (2015) used data binding to detect outlier and generate context to parallel coordinates. The system was able to handle datasets of up to 25 million records (Fig. 1).

Pixel-Oriented Visualization

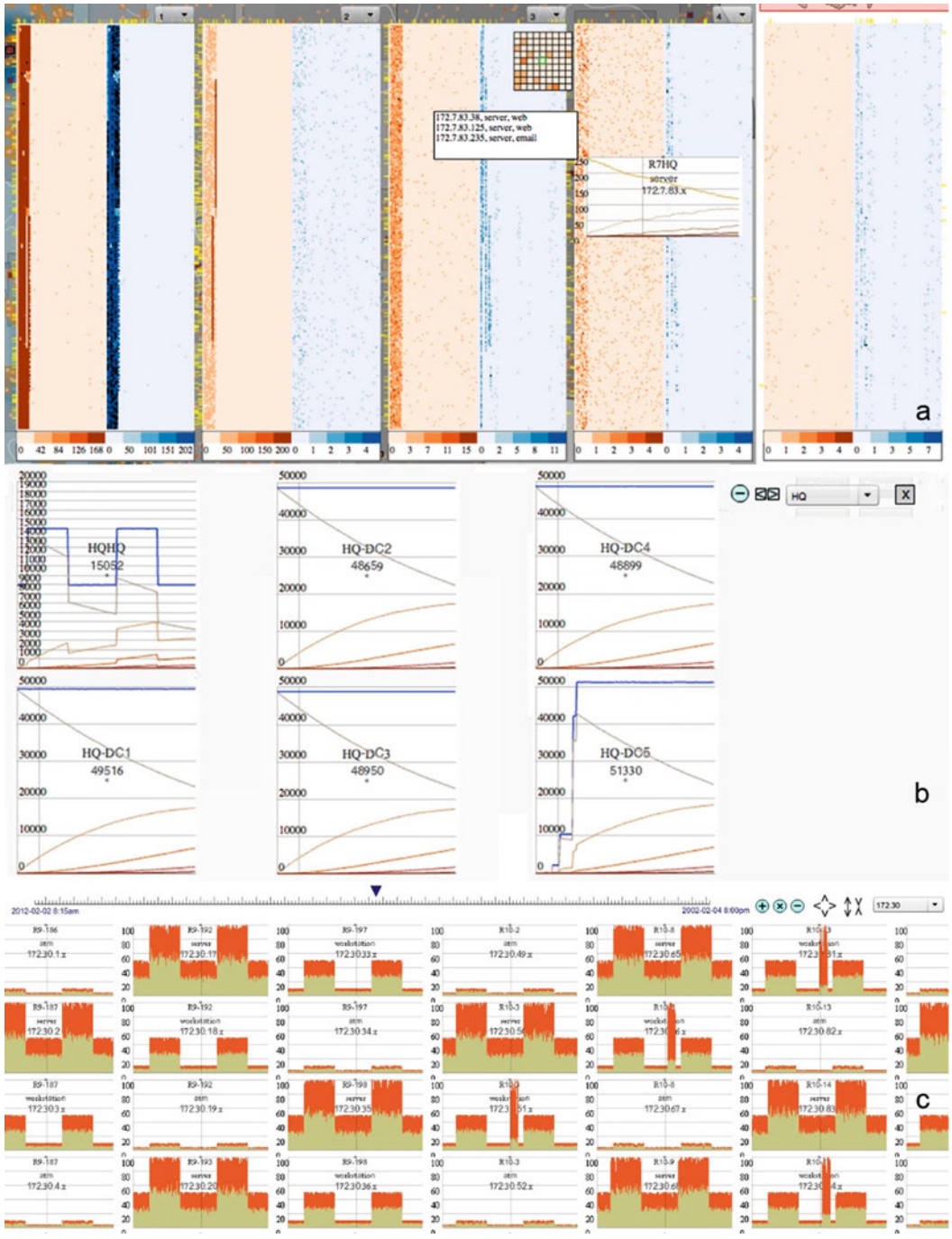
Pixel-oriented visualization aims at representing as many data records as possible on the screen by mapping each value to a colored pixel and arranging the data values based on the inherent ordering of data objects within the separated sub-window (Keim 2000). The early approaches of pixel-oriented visualization include high information density displays like Eick's SeeSoft that allowed users to analyze up to 50,000 lines of code simultaneously by mapping each line of code into a thin row for finding interesting patterns (Eick et al. 1992). Scheepens et al. (2011) presented an interactive approach to visualize trajectories with multiple attributes using density maps. Density maps can be used to display more than three million data points with a density field of 1250 × 1020 cells on a screen of 900 × 900 pixels. Chen et al. (2015) presented cyber security datasets, which contained millions of computers on the pixel-oriented visualization. The IP block pixel-based visualization had three levels. Mouse over Fig. 2a can see enlarged pixels. Clicking a pixel would evoke the corresponding time series curves of the pixel on Fig. 2b. Users are able to notice abnormal patterns in Fig. 2b. Clicking on one curve would evoke more detailed information presenting on Fig. 2c.

Hierarchical Presentations

Hierarchical presentations include treemaps, dimensional stacking, star glyph, and texture. The hierarchical techniques subdivide the k-dimensional space and present the subspaces in a hierarchical fashion (Keim and Kriegel 1996). Dimensional stacking technique is widely used for the visualization of multiple time series data. ThemeRiver was a novel visualization method to represent thematic variations over time where the layers were stacked in a symmetrical shape along the x-axis (Havre et al. 2000).



Scalable Techniques to Visualize Spatiotemporal Data, Fig. 1 The parallel coordinate with eight dimensions presents 25 million movement records within an amusement park (Reprinted from Wei et al. 2015). In sequence, the dimensions are group index of visitors, visitors' walking steps within the park, the times of entering the park, the population of the group, the taking number of thrill rides, the taking number of kiddie rides, the taking number of everyone rides, and the taking number of show rides. With interaction, outliers can be detected accurately



Scalable Techniques to Visualize Spatiotemporal Data, Fig. 2 Pixel-based visualization of IP blocks (Reprinted from Chen et al. 2015). **(a)** Each pixel represents a group of computers, **(b)** the curves of policy statuses, activities, or the number of connections curves of the selected pixel, and **(c)** zoom in to show the detailed graphs of the number of connections

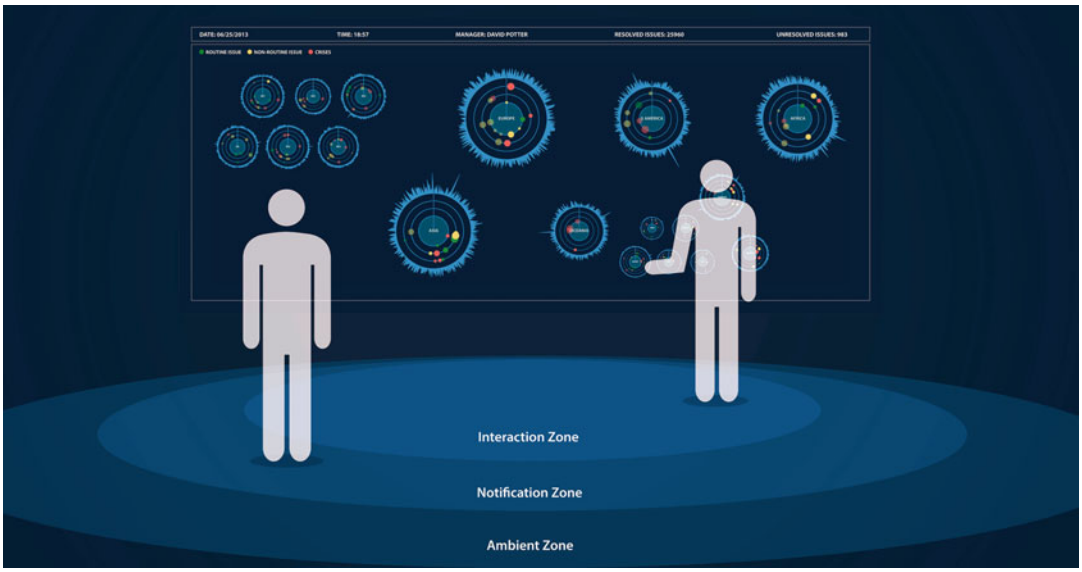
The NameVoyager used a set of interactive and color-coded stacked graphs to visualize hierarchical time series. It enabled users to explore a set of 6000-time series (Wattenberg and Kriss 2006). Wongsuphasawat et al. (2011) used colored triangles on a horizontal timeline to analyze large numbers of event sequences. In LifeFlow, more than two million incidents could be displayed to support users' exploration. However, stacked graphs may mislead audiences because the boundaries of each layer lie in the continuous curving lines. The varying baseline of the layout will also make the overall graph much harder to read.

Beside typical hierarchical presentation, researchers also proposed some novel hierarchical interactions. As is shown in Fig. 3, SolarWheel (Chang et al. 2013) allowed multiple analysts to interact with the display. Different hierarchy levels would be present according to the analysts' distance to the display. The combination of hierarchical structure and interaction, the display can present millions of data according to the requirements of analysts.

Display Scalability

According to Cook and Thomas (2005), most visualization systems only fit the common desktop display (1280 × 1024 pixels). It is important to develop techniques that scale to various display such as a wall-sized display, a PDA, or a phone-sized display. Cook and Thomas (2005) stated that the major challenge was to develop interaction techniques that were displayed scale-independent, particularly on small displays.

Rønne Jakobsen and Hornbæk (2011) designed a controlled experiment to compare three classic interactive visualization techniques – focus + context, overview + detail, and zooming with varying display size (13.8, 1.5, and 0.17 megapixels). The results showed that overview + detail worked best across different display sizes, while focus + context was more difficult to use at a small display size. As a display-scale independence design, FacetMap used a space-filling metaphor to allow users to browse and search for facet values (Smith et al. 2006). FacetMap was able to work on any size display and adapted its



Scalable Techniques to Visualize Spatiotemporal Data, Fig. 3 The display monitor will detect the sight direct and the standing distance of analysts to decide the stats of Solar Wheels (Reprinted from Chang et al. 2013). When an analyst is in the ambient zone, the highest level of the hierarchy will be present to give an overview. When analyst goes into notification zone or interaction zone, the Solar Wheels will split into small wheels to show the lower level, the volume of data will be depicted to analysts

information layout to reveal more information with larger displays. However, because displaying information on the phone-sized screen required too many effective interactions, FacetMap needs more effort to get down to small displays. Many existing techniques are usually limited to explore large data items using mobile and handheld computers such as personal digital assistants (PDAs) or subnotebooks. Many researchers have tended to adopt a second approach that is to use the small screen as a window onto a larger virtual space (Gutwin and Fedak 2004). Gutwin and Fedak (2004) compared three techniques for using large interfaces on small screens: a panning system similar to what was in current use, a two-level zoom system, and a fisheye view. They tested these techniques with three realistic tasks and found that people performed faster with the fisheye view, that the two-level zoom was significantly better for a monitoring task, and that people were slowest with the panning system.

SpringRain (Promann et al. 2013) combined display with Google Glass to present overview and detail information for users (Fig. 4b). The overview presentation can be applied to varying display sizes such as wall-size or computer monitor size (Fig. 4a).

Human Scalability

Cook and Thomas (2005) reported that human skills and abilities were fixed and did not scale, but the number of humans involved in analytical problem-solving and response activities did scale. Researchers should develop techniques that scale from a single user to a collaborative environment. Users may be collaborating from within the same team in an organization, at different levels of an organization, or even in different organizations.

Geocollaboration is regarded as the use of a visual display by two or more participants to frame and address a problem or to complete a task (MacEachren 2001). Schafer et al. (2007) developed a geocollaboration tool to support community-wide emergency management planning and preparedness. The software architecture was beneficial to the design and implementation of geocollaboration applications. Issues such as emergency vehicle traffic routes and staging areas for command posts, arriving media, and personal first responders' vehicles can be examined together and collaboratively through the software. Besides situations like crisis management and building planning, geocollaborative tasks can also support a situated learning activity to train students in acquiring IT skills. Baloian and Zurita (2016) proposed a geocollaborative application including georeferencing and microblogging-like messages to support the pedagogical activity. The evaluation provided positive results for the geocollaborative application and offered valuable insights on the implementation of a collaborative visualization system to support learning activities for large groups.

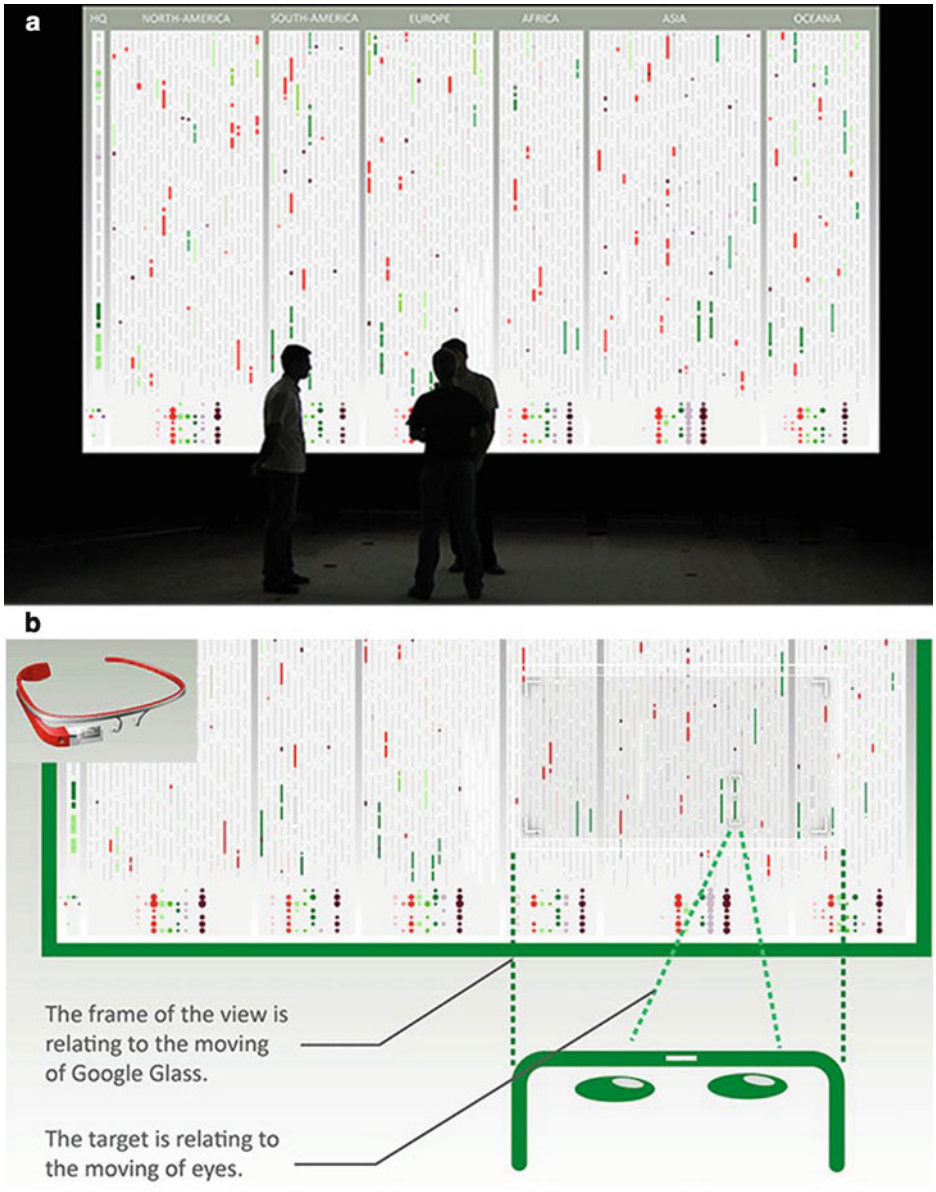
Software Scalability

The capability of software systems to be configured to interactively manipulate data sets of various sizes is called software scalability (Cook and Thomas 2005). This includes the generation of new algorithms that scale to the ever-increasing generated information sets.

WiGis was able to support user interactions with large graphs in a web browser without the need for plug-ins or special-purpose runtime systems (Gretarsson et al. 2010). The researchers found that the main scalability limitation was because most of the systems implemented some form of a thick client solution and subsequently needed to load the entire graph onto the client machine. WiGis circumvented these limitations by leveraging a novel technique for storing and processing graph data on a powerful remote server. To achieve fast processing, Zinsmaier et al. (2012) extended Kernel Density Estimation (KDE) for node aggregation by a two-pass seed point rendering. This technique significantly reduced geometry and scaled to large graph with millions of nodes and edges.

Case Study: A Polygon-Based Visualization Approach to Display Large GPS Tracking Data

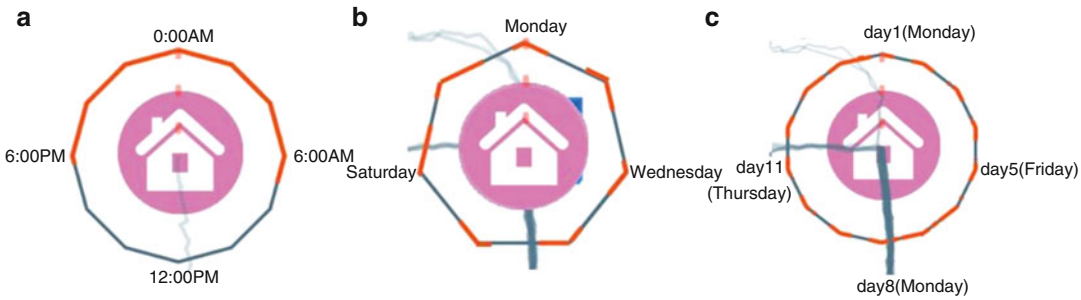
This section demonstrates our design concept that can be used to visualize human life patterns from a



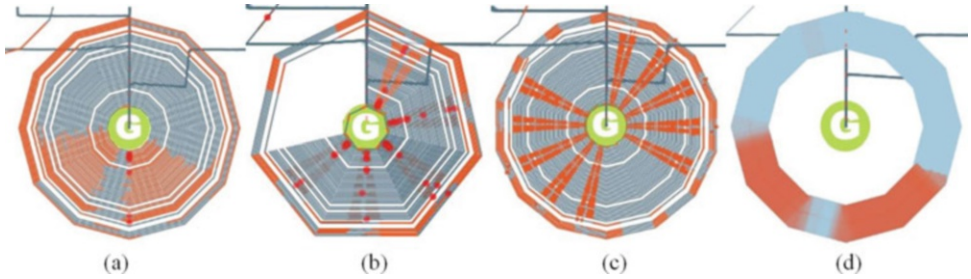
Scalable Techniques to Visualize Spatiotemporal Data, Fig. 4 (**a**) the SpringRain is applied to the wall-size display. (**b**) Google Glass shows detail information according to the moving of glasses and eyes (Reprinted from Promann et al. 2013)

large GPS tracking data set. The system won an award in VAST Challenge 2014 (Guo et al. 2014). 2014 VAST Mini-challenge 2 data are used to study daily routines because the simulation data contain timestamp, latitude, and longitude and show high fidelity on spatial and temporal attributes. The dataset contains 70 million GPS records, 1500 credit card transactions, and 1400 loyalty card transactions for 40 cars during 2 weeks.

Researchers designed n-side regular polygons on a map to visualize time and geographical locations of GPS data within a single view. Polygons with different sides are able to show different



Scalable Techniques to Visualize Spatiotemporal Data, Fig. 5 (**a**) One dodecagon shows one subject's daily activities at home. This subject stays at home from about 6 pm to 7 am. (**b**) One heptagon denotes one subject's weekly activities at home. Audiences can tell that this subject frequently arrives at home before midnight and leaves home in the morning. He stays at home most of the time during the weekends. (**c**) One 14-sided polygon represents one subject's activities during 2 weeks. It is enough to show this subject's weekly routine. This subject leaves at home early in the morning, goes back home directly after work, takes a short rest, and goes outside. He usually returns home before midnight



Scalable Techniques to Visualize Spatiotemporal Data, Fig. 6 (**a**) Nested dodecagons to show subjects' activities at the company in 1 day. (**b**) Nested heptagons to show subjects' daily activities at the company in 1 week. (**c**) Nested 14-sided polygons to show subjects' weekly activities at the company during 2 weeks. (**d**) One thick ring with color shades to show the frequency of stay regarding a large number of subjects

periods. Each side of a polygon can represent 1 day, 1 week, 1 month, or 1 year. As is shown in Fig. 5a, one dodecagon can represent 1 day with each side denoting 2 h. The orange segment marked on the dodecagon corresponds to the periods of stay. Figure 5a shows that the subject goes back home at around 6 pm and leaves home at around 7 am. A home logo is placed in the center of the dodecagon as a point of interest. One heptagon is suitable to show subjects' weekly routine, and the orange segments reveal start and end times as well as the time range of home stay (Fig. 5b). A 14-sided polygon is drawn to display the subject's daily activities during 2 weeks (Fig. 5c). Figure 5c shows that the subject frequently comes home after work and then goes out for dinner. He usually returns home before midnight and leaves home in the morning. Thus, the polygon-based visualization flexibility displays periodic time series and can be scaled to visualize large volumes of time series data.

Regarding a large number of subjects, polygons can be nested together on a map to present a set of subjects and reveal events occurring while the subjects occupy places at times. Figure 6 shows 40 subjects' activities occurring at the company. Each polygon represents one subject. Nested polygons from inside to outside denote subjects from the first to the 40th. There is a company logo in the middle of the concentric polygons, which presents the location type. The orange segment corresponds to the stay range, and the red dot on a segment represents a credit card transaction.

Figure 6a shows the subjects' 24-hour activities at the company. Nested dodecagons tell us

that most of the subjects go to work at around 8 am, leave the office for lunch, return to work at around 2 pm, and leave the office at around 6 pm. Audiences can also see that several subjects spent some money around noon based on the position of red dots. Figure 6b displays subjects' daily routine in 1 week. Nested heptagons show that most of the subjects go to work during the weekdays and leave office during the weekends. A few subjects stay at the company during the night and leave it in the afternoon. The weekly life pattern is also very clear in the 14-sided concentric polygons for 2-weeks' data (Fig. 6c). To cope with large datasets, a thick polygon is designed to scale the data to visualize a large number of subjects without overlapping or visual cluttering. As is shown in Fig. 6d, the graph uses one thick ring instead of nesting dodecagons to show subjects. The stay range with the highest density determines the thickness of the ring. Color shades on the ring correspond to the percentage of stay range. Deeper yellow colors denote more frequent stays, and lighter yellow colors represent shorter stay periods in 1 day. Thus, the visualization can show an overview of many subjects with aggregation for a certain period.

In this study, researchers use polygon as the main metaphor to record subjects' temporal activities during different periods. Nested polygons on a map can present a large number of subjects' routine. With the polygon-oriented glyph design, analysts can view regions of interest at different levels of periodic time series.

Conclusion

This entry provides a detailed overview of the current scalable spatiotemporal visualization techniques from the perspectives of information scalability, visual scalability, display scalability, human scalability, and software scalability. A case study demonstrates how a polygon-based visualization is used to display a large number of GPS tracking data. However, a big limitation of the design is that the inner polygons are smaller than the outer ones and it may not be easy for audiences to discern information from small polygons. With massive amounts of information drawn on polygons, a thick ring can only show the overview of temporal patterns while losing the details of individual activities. Authors admit that the presented concept in this entry is simple and easy to implement. This entry does not introduce new visual approaches to encode time series data. Our idea is just to provide a flexible and consistent way to display different levels of time series with a variety of different visualizations. The drawing metaphor is intuitive to audiences, and the method is very easy to use. Integrating the visualization method with GPS tracking data would empower the analysis of human life patterns of sparsely sampled data.

Cross-References

▶ 3D Visualization Interface for Temporal Analysis of Social Media

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Scatter Chart

► Multivariate Visualization Using Scatterplots

Scatter Diagram

► Multivariate Visualization Using Scatterplots

Scatter Graph

► Multivariate Visualization Using Scatterplots

Scattergram

► Multivariate Visualization Using Scatterplots

Scatterplot

► Multivariate Visualization Using Scatterplots

Scene Graph Engine

► Panda3D

Scripting Environment

► Character Animation Scripting Environment

Scripting Language

► Character Animation Scripting Environment

Secure Gaming: Cheat-Resistant Protocols and Game History Validation

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Synonyms

Anti-cheat protocols; Cheat-resistant gaming; Game integrity validation; Game state validation

Definition

Cheat-resistant protocols and game history validation are design approaches to limit and reduce cheating in massively multiplayer online (MMO) or multiplayer games. Cheat-resistant protocols follow design principles that reduce or eliminate cheating through alteration of game communication. Game history validation is a method to ensure the integrity and consistency of dynamic and static game state to identify and correct cheating attempts.

Motivation

In forums, MMOs, and multiplayer games, it is common to find stories about cheaters and the issues they cause. Posts describe how other players have impossibly powerful characters, seemingly ignore game rules, or quit a game right before a loss without penalty. Excessive cheating can cause players to avoid an otherwise fun game and result in severe losses for game developers and publishers.

Cheating is not a recent phenomenon, cheating in games has an equally long history as online gaming itself: one of the first peer-to-peer networked multiplayer games, Maze War, was released in 1975 and soon after its release altered clients were available that provided a god-like view to make all other players visible.

Gaming has drastically changed and matured since then. Online games and MMOs are more popular than ever (Valve 2015). E-sports and in-game economies are increasingly backed by real money and require robust security and cheat detection. Now multiplayer and MMO game design is at a stage where game developers are no longer investigating *how* to build these games, but rather how to build them *more securely and efficiently.*

Any competitive multiplayer game needs to be built from the ground up to resist cheating. This entry will illustrate the general principles for cheat-resistant protocol design and then show how to build a secure peer-to-peer protocol that provides strong cheat resistance even if malicious players are present.

Background: Cheat Taxonomy

Cheating can be defined as "the action of pretending to obey the rules of the game, while secretly subverting them to gain advantage over an opponent" (Thompson 2007). Cheating therefore covers a wide area of possible attacks, both technical and nontechnical, and it is important to understand possible attack paths before creating defenses against them:

1. **Active game state attacks**
   Instead of passively exploiting game logic, active attacks change game state outside of game logic either by altering game data (stored on disc or in memory), executables, or communication. Examples of active game state attacks are: save game editors that change stored game state on disc, game trainers that alter game state in memory, wall hacks that reveal hidden players, or traffic shaping tools that allow to alter selective network communication (Hoglund and McGraw 2008; Table 1).
2. **Passive game exploits**
   These attacks are against game logic or game flow and exploit missing limits or bugs to benefit the attacker. Instead of breaking outside of the game rules, the cheater primarily stays within the system to gain an advantage. Examples of passive exploits are: game design exploits like repeatability of a highly rewarding game objective, timing glitches that allow for in-game item duplication, or benefits from service disconnection. These types of exploits can often be addressed through gameplay design changes or code bug fixes and will not be covered in detail here (Table 2).

To provide perfect cheat resistance, defenses against all of the previously mentioned attacks and exploits are needed.

Background: Existing Solutions

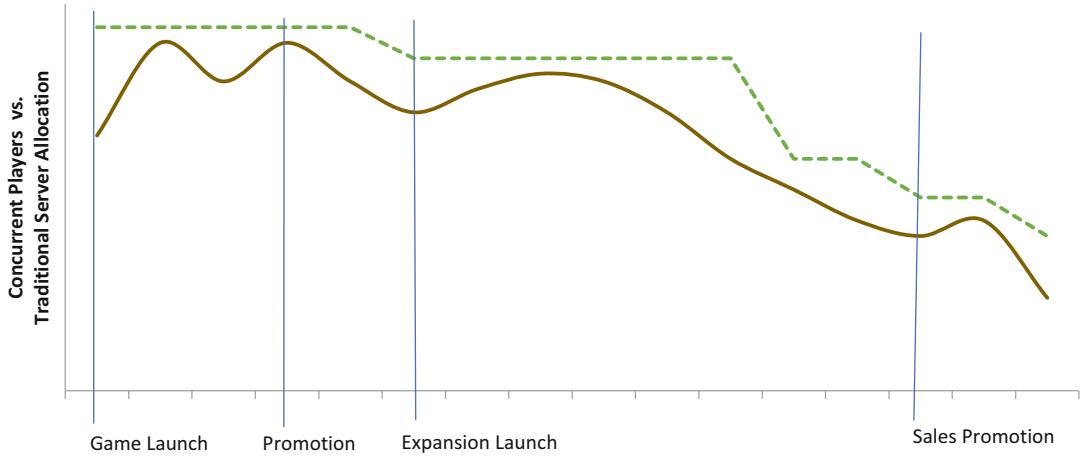
Nearly all attacks in online games are more effective when the cheater is also the host of the

Secure Gaming: Cheat-Resistant Protocols and Game History Validation, Table 1 Examples of active game state attacks

Exploit area	Example
Local data	Save data manipulation, wall hacks
Local functionality	Executable manipulation
Network/service communication	Traffic alteration, client, or service impersonation
Game ecosystem	Social engineering

Secure Gaming: Cheat-Resistant Protocols and Game History Validation, Table 2 Example list of passive game exploits

Exploit area	Example
Local execution	Game timing exploit
Local functionality	Game design exploit
Network/service communication	Disconnection, traffic shaping
Game ecosystem	Social engineering



Secure Gaming: Cheat-Resistant Protocols and Game History Validation, Fig. 1 Concurrent player count (*solid line*) vs. server allocation (*dotted line*) – with a single datacenter, overallocation of servers is needed. Best fitting available server resources to the player curve requires constant tweaking and initial overallocation. In contrast, the cloud can be fit tightly to the player curve

gameplay simulation. Therefore, most games either limit or prevent cheaters from hosting either by randomizing peer hosting or using dedicated game servers (Aldridge 2011; Weilbacher 2012).

Randomized peer hosting does not prevent a cheating host, but it aims to reduce the probability of a cheater as host. It does so by randomizing host selection. Instead of matching the host predictably (e.g., the first player or the player with the best network connection), multiple host candidates are identified and a random host is then selected from the candidates. This added complexity can eliminate automated cheating attempts, but it is often possible for a more sophisticated attacker to manipulate the candidate selection through traffic shaping (e.g., eliminating other host candidates through filtering).

To avoid peer hosting issues altogether, game developers and publishers often choose to focus on closed console platforms and host servers in datacenters. This approach limits the attack vector of cheaters and provides increased security over peer-to-peer gameplay by putting most of the game logic into a controlled environment. It allows full, ongoing game state control and monitoring. For this approach, the client is often only a viewport into the state of the dedicated server. The less logic a client is responsible for, the more cheat resistant this design is.

However, game servers require significant ongoing financial investment. Single datacenter hosting has to exceed concurrent player numbers (Fig. 1) and can cause scalability bottleneck when player numbers spike.

To limit cost impact, developers and publishers increasingly turn to cloud services to host game servers (Shiring 2013). Adding and removing cloud servers is less costly and server resources can be fitted more tightly to concurrent player counts. Cloud services are also able to absorb unexpected usage spikes during the lifetime of a game more easily than dedicated datacenters.

Despite these benefits, cloud hosting is not a perfect solution for all games. Cloud servers still have ongoing operational cost that can be prohibitive for smaller games and studios. In addition, server-based games have a very finite lifespan: when servers are shut down, the game is not playable anymore. This hard sunset can often alienate even the most dedicated players.

The following design shows an alternative to cloud hosting by building a peer protocol that provides similar security and cheat resistance but with minimal server costs.

Secure Gaming Design Basics

When designing a new system, it is best to start by determining which security and anti-cheating guarantees that are needed. Independent of game type or game mode, the following guarantees are essential for any cheat-resistant design:

1. *Strong player identities*
   Players should not be able to participate in multiplayer gameplay without presenting a strong proof of identity. Such identities should be a scarce resource and costly to replace. Strong identities can be used to uniquely identify cheaters and punish them if needed.
2. *Message integrity and authenticity*
   Any type of message between players needs to be protected from modification and replay attacks. Furthermore, message authenticity has to be verifiable. Without these guarantees, cheaters can assume other identities and manipulate messages of players and services. For most games, message confidentiality is also essential to cheat-resistant game play.
3. *Limited information*
   Any nonpublic game state should only be shared with game clients that need it for logic purposes. This eliminates the possibility for cheating players to assemble a full game state view and observe actions that should be hidden (wall hacks).
4. *Gameplay verifiability*
   Gameplay actions need to be verifiable. Given a set of starting conditions and game actions, a game client should be able to determine if all game actions were valid and which final outcome is expected. Verifiable gameplay allows the identification of current and past cheating attempts.

A system that provides these guarantees can provide cheat-resistant gameplay. Guarantee 1 and 2 can be implemented directly through general-purpose security solutions. Guarantee 3 is more complex: the flow of game state between players needs to be closely examined and any unnecessary/unobservable information should be removed. This impacts the complexity of the game engine and reduces latency tolerance but it greatly decreases possible cheat vectors.

Guarantee 4 is essential for any type of cheat detection, specifically in a peer-to-peer model without a secure server host. In this model, clients need to be able to verify the actions of other untrusted peers. How to achieve this is not immediately obvious: by definition, a peer-to-peer network has no single arbiter. It may therefore seem futile to even attempt to create a cheat-resistant peer-to-peer system.

However, when looking at games, the vast majority of players will fall into one of the three categories:

1. Casual players that are participating in a friendly game with their friends. These players are highly unlikely to cheat due to the casual nature of their gameplay.
2. Competitive players that see the game as a challenge. These players rarely consider cheating since it would detract from the challenge of the game.
3. Opportunistic cheaters that will use exploits or cheats only if they are easy and risk-free (e.g., item-duplication glitches). These players generally do not actively participate in cheating.

Only a tiny fraction of players will attempt active cheating through active game state attacks. In other words, when looking at a larger sample set of players, the *honest* players will be the majority. This insight can be used to build a protocol that uses game simulation results of the combined player base to reach a consensus through voting.

In voting a system, multiple untrusted components perform the same computational operations and each component "votes" with its computational result. The result with the majority of votes becomes the global consensus result of the system. This approach is used in redundant fault-tolerance to identify processing errors for critical systems like aviation control (Lyons and Vanderkulk 1962). The underlying assumption in these systems is that the error results (similar to cheating players) only occur rarely.

The same principle can be applied to cheat detection as well. Assume that any given player is a cheating player with a probability of $\frac{1}{c}$, which (as noted before) is rather small for most games. When looking at a group of n players, the chance of picking a group that consists of only cheaters is $\left(\frac{1}{c}\right)^n$. For large n and c, the probability of having a group of cheaters decreases therefore quickly. A vote in a large group of players should be dominated by honest players and cheaters should be the minority. To be more precise, the probability p that $\frac{1}{x}$ of the players in a group of n are cheaters is $p = \left(\frac{1}{c}\right)^{n/x}$. This probability is critical: it has to be low to ensure an honest outcome for most votes. Once $\frac{1}{c}$ is estimated for a game, it is possible to tune the number of players (n) such that a satisfactory probability value p exists for a value of x. The result then determines a minimum group size for gameplay verification. For competitive games the value for x should always be greater than two to keep cheaters in the minority and ensure an honest consensus.

In practice, the exact group size may be hard to calculate because c has to be estimated. However, for any sizeable group of players (typically more than five) it is safe to assume that there are more honest players than cheaters. As a result, for any vote on game actions a majority of the votes should come to the same honest (i.e., non-cheating) outcome. In a predominantly honest group, it will therefore always be possible to identify cheaters as nonmajority votes are highly likely cheating attempts.

A voting system like this is very powerful and it is obvious that it will be valid as long as the majority of the player base is honest. It could be possible that cheaters are clustered and a group of players consists predominantly of cheaters. This may seem problematic. However, this only has limited impact because of the way cheating is generally performed. It is unlikely that cheaters collaborate in game modes with a single winner. Each cheater will attempt to manipulate the gameplay in a different way, resulting in different individual votes. In this scenario only honest players will be in agreement about game state and in the worst case no consensus is reached. A lack of consensus still signals a cheating attempt, although it may not be possible to identify which specific players were cheating. The same detection is possible for team-based game modes. If cheaters collaborate within a game of balanced teams they have a maximum of ½ of the total votes. This is insufficient for a majority of votes, again signaling a cheating attempt. In both scenarios the game session can be stopped or canceled and investigated further if needed.

This means that in practice voting is at least able to identify that cheating occurred, and in most cases it is also able to identify which players attempted to cheat.

Peer-to-Peer Protocol Design

With the basics for gameplay verification in place, the first design challenge for a peer-to-peer system is authentication. As mentioned before, a cheat-resistant system needs a strong player identity. Without a strong player identity, it is not possible to leverage the power of the combined player base – cheaters are then able to create zombie accounts and swing votes in their favor.

Nearly all game consoles and mobile and game distribution platforms already provide a basic player identity (or *profile*) information and an accompanying, secure authentication system. This platform identity and any accompanying authentication tokens can be used as the base of identity of a player in the game. In case a basic player identity is not available (or it cannot be used), an identity system has to be created. The core functionality to consider is in providing secure user authentication under *all* circumstances; multiple, well-known authentication protocols exist for such purposes, and it is unsafe to create a custom, untested protocol. It is also important that user identities are a *constrained* resource.

For an example system, we assume that user accounts are tied to game keys and that a secure login server is needed to start any multiplayer session. The login server will also provide a verifiable identity token for later use. This first peering step is called [`Authenticate`].

Now that it is possible to build a set of authenticated players, the next step is to construct a peer-to-peer mesh. The main security challenges here are integrity and efficiency. Only authenticated players should be able to connect and any new players should find other players as quickly as possible. To join a peer-to-peer network, a new player needs to know at least one other active peer node. The distribution of such initial peers should be the final step during player authentication. Either the authentication system keeps a list of active peers and selects a suitable subset for the new player or a handoff to a dedicated peer-to-peer tracker or dictionary occurs. The tracker is also responsible for verifying that peers are still connected to the network and providing updated peer selections when more connection points are needed. For security purposes, the peer selection should not be predictable, otherwise cheaters may be able to create cheating clusters in the network.

In the example system, we assume that we have a small set of trackers available. These will provide known, valid peers to any new peer with a valid authentication token. We call this step [`GetInitialPeers`].

A centralized tracker still requires datacenter resources. But unlike a client/server design it is very lightweight and can be built as a simple web service. A tracker only handles client lookups and infrequent pinging and scales to very large numbers of concurrent players without any significant investment in hardware. At the end of life of a game it can also be handed off to the fan base, keeping the most vocal and hardcore fans happy well after the game's shelf life has expired. An alternative to a centralized tracker is a peer-to-peer tracking system which keeps localized routing data on every peer in the network.

Next, message authenticity and integrity guarantees are needed. A standard solution for this is to encrypt all pairwise communication between peers. Each new peer connection should start with a security handshake that establishes any encryption keys and secrets for pairwise connections. It is safest to assume that encryption only provides confidentiality. Digital signatures and *sequence numbers* must be added to provide message integrity and protection from replay/message injection attacks. To prevent unauthorized peers from joining, the handshake also needs to verify the initial authentication token.

In the example system, we can satisfy these requirements by first using TLS/DTLS to select unique encryption and signature keys and share an initialization vector for encryption. We then use the encryption key and initialization vector for AES encryption with CBC as a block cipher mode for pairwise communication. As a final step, we verify the identity of a peer through the authentication token that was provided by the login server. If it is invalid, the connection is terminated. We call this secure connection step is [`SecurePeerConnect`].

This step has to be repeated for each peer node that joins the gameplay session. In addition, peers that drop from the network for any reason need to be replaced. (In the example system, a peer has to contact the tracker to retrieve replacement peers.)

Game History Validation Design

The next step after the previous peer-to-peer system design is to design a voting and gameplay verification system. This design depends on the game type and falls into two classes: in multiplayer games like FPS shooters, MOBAs, or strategy games, gameplay messages only propagate between a limited set of players and game state is transient. Gameplay data, except updates to the player's profile, does not persist longer than a short, single gameplay session. In contrast, MMO games have to propagate game updates amongst a very large set of players and need persistent game state.

Validating Transient Multiplayer Games

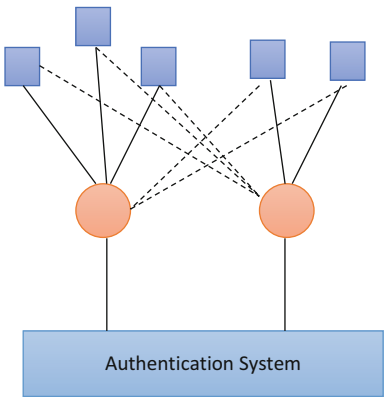
The two biggest problems in transient multiplayer games are how to find peers for gameplay verification and how to synchronize gameplay effectively.

One approach is to use lightweight game state validation through a state digest. This is only

feasible with a game engine that uses a fixed time step simulation. At a synchronized time interval in the simulation, each peer performs a one-way hash *H()* over a limited set of important game state objects *obj*, the timestamp *t,* and local player identity *id. H(obj,t,id)* is then called the local state digest. Each peer sends the local *H(obj,t,id),t,id* through a secure and reliable channel to all other peers. Other peers are then expected to validate these digests. Due to network latency, this may occur with significant delay and local copies of not yet validated *obj* for a specific *t* need to be stored. When a remote digest is received at a later time, it can be validated by creating an expected digest and comparing it to the received digest. The expected digest is created using the local game state with the remote identity: *H(obj_local, t_local,id_remote)*. If the expected digest does not match the received digest, the remote game state was altered. At this point, the peer can disconnect from gameplay and report which client was the suspected cheater. For additional safety, missing digests should also be interpreted as cheating attempts after a specific verification timeout has expired.

A more accurate cheat detection is provided by a two-tiered peer architecture design. Here, peers are divided into trusted and regular peers. A small set of trusted peers from the overall peer population serves as the arbiters and manage the other peers. We will call these trusted peers *supernodes*. These supernodes have proven over time that they are trustworthy and very unlikely to be cheaters, so their resources and trustworthiness can be used more reliably in the overall verification system. In the example system, we keep this trust information on the tracking service for additional security.

To enable gameplay validation, pick and assign at least one supernode to each existing game mode (e.g., deathmatch vs. capture the flag). It is preferable to assign multiple supernodes for redundancy and scale the number of supernodes based on popularity of a game mode. When new players join the peer-to-peer network, we now modify [`GetInitialPeers`] so they are first routed to the supernodes for their game type instead of regular peers. Supernodes then divide new peers into gameplay groups and provide the peer set to the joining peer. A gameplay group is the traditional set of players in a gameplay session. Additionally, new peers are joined to the supernode as a voting peer and may be called upon at a later point to vote on game actions. We call both join actions [`GetSecondaryPeers`]. All voting actions are handled through a dedicated connection, different from the gameplay connection. Each verifying peer is connected to at least one supernode and should never verify its own gameplay sessions. Gameplay actions are now executed and verified in the following way: when a peer performs a game action, its peers in the same session are updated directly in the same way traditional game clients would be. We call this action [`UpdateGamePlay`]. In addition, the peer sends its action and relevant game state to the supernode. The supernode forwards verification information to a set of verification peers and requests a vote. This set of peers should never be in the same game session they verify and can be across game modes (Fig. 2). Each verifying peer executes the action and returns with one vote. The supernode can then confirm or reject the gameplay action to the gameplay peer. We call this action [`VerifyGamePlay`].



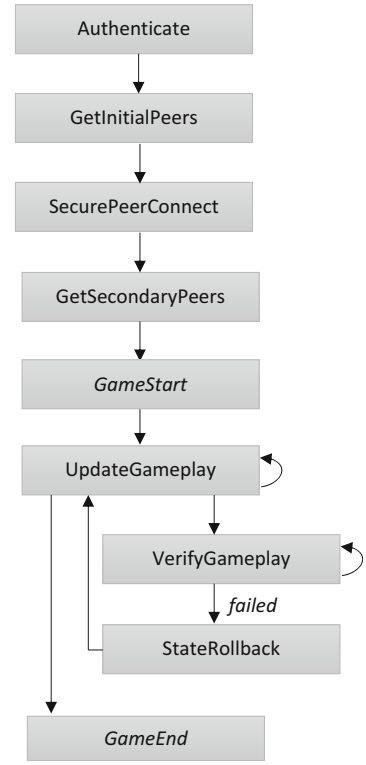
Secure Gaming: Cheat-Resistant Protocols and Game History Validation, Fig. 2 Simplified dataflow between authentication system, supernodes (*red*), and peers (*blue*). Gameplay and authentication flow is shown as a *solid line*, verification flow as a *dashed line*

Dependent on peer network resources, it may not be possible to verify all gameplay actions in all session types. A set of peers with very limited network bandwidth or incomplete connections will not be able to duplicate all game actions without impact to general game flow. Fortunately, we can often rely on the game flow for such scenarios. In nearly all games, cheating attempts are not singular events; they cause long-lasting impact on the game state. Therefore, even verifying only high-risk game actions or a set fraction of game actions can effectively reveal cheating attempts.

Verification cannot be performed as quickly as a local gameplay action. In addition to verification time, it requires at least one round-trip each between the gameplay peer/supernode and supernode/voting peer. Peers can work around this delay by opportunistically executing gameplay actions before a vote is complete. All gameplay actions are temporary accepted, but not committed until a vote confirmed. For this, the peer keeps an action history to roll back any action that is rejected at a later point. While it is not desirable to have rollbacks during a game session, they are expected to be very rare. Specifically, rollbacks should only occur during a cheating attempt. At the point of a cheating attempt, players will prefer a rollback rather than continuing with a cheated game state, even if it impacts the continuity of a game. We call this rollback action [`StateRollback`].

Once a supernode rejects a gameplay update, it can also isolate the offending peers and react appropriately. The reaction can vary from removing the cheating peers from the gameplay session and mark the cheating attempt on their profile to an immediate ban from the network.

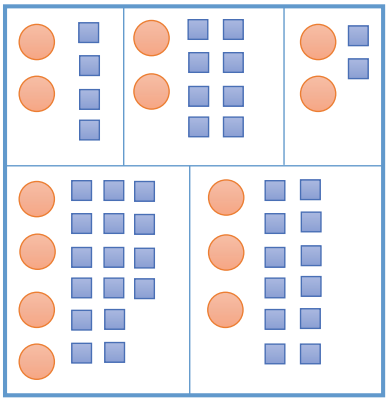
It is important that supernodes are verified on a regular basis to detect any malicious behavior. When multiple supernodes are assigned to one game mode, they can arbitrarily verify each other's behavior and the voting results that are sent to the peers. If a cheating attempt is found, the offending supernode can be reported to the authentication service. Here, it can be removed from the list of trusted peers.



Secure Gaming: Cheat-Resistant Protocols and Game History Validation, Fig. 3 Event flow for a standard peer

Validating Massively Multiplayer Games

These types of games can use the same voting design (Fig. 3), but gameplay updates need to be extended to take persistent game state storage into consideration. As a result, different segmentation of supernodes is needed. Instead of segmenting supernodes by game modes, the MMO game world is segmented into *chunks*, which represent game areas. The number of chunks will be static in most games. One supernode can handle multiple chunks, but each chunk should have at least two supernodes assigned to it for failsafe (Fig. 4). When players move into a chunk in the gameworld, they transfer to one of the associated supernodes. A chunk to supernode mapping can



Secure Gaming: Cheat-Resistant Protocols and Game History Validation, Fig. 4 Segmentation of MMO game world into chunks. Each chunk contains multiple supernodes (*red*) based on client (*blue*) population. Chunks do not need to be of equivalent size in the game world

either be provided by the tracker or negotiated amongst supernodes. This approach is similar to segmentation in peer-to-peer file sharing networks like BitTorrent and has the same constraints (Pouwelse et al. 2005).

The supernodes of a chunk and all connected peers keep its game state. Like in the previous design, game actions are executed and voted on. Similar to before, peers should not vote on actions in their own chunk to reduce the incentive for cheating. Players are less likely to cheat if it does not affect them directly.

In a system where all data is stored on peers, a high peer churn can cause issues. Therefore, it is important to ensure that game information is updated in a shared database in addition to the game state that is held on supernodes. Updates can be performed asynchronously from each supernode and merged into a time stamped game state in the shared database. This shared database could itself be a peer-to-peer system, single system, or a cloud-based solution.

Multiple copies of the same game state and a large population can significantly reduce the need for frequent backups. By requiring at least two supernodes per chunk, we can ensure basic redundancy. Further redundancy is provided by connected peers; they also keep parts of the game state. When peers leave, the supernode can provide the needed game state to new peers. When a supernode has to be replaced, the secondary supernode can be used for bootstrapping. If a conflict in states of multiple supernodes is detected, it is treated similarly to a mismatch in a game update vote.

Not relying on a shared database will work as long as sufficient supernodes and peers are present. As a result, during the early, high population lifetime of a game (Fig. 1), the shared database will only provide an auxiliary service. As time progresses and player numbers drop, the shared database will increase in importance. It becomes essential when chunks only have one supernode. It then serves to bootstrap any chunks that have lost their last supernode or are devoid of peers and supernodes.

Summary

This entry shows how to use consensus voting amongst the player population of a game to detect cheating attempts and reviews which general identity and security guarantees are needed for building a cheat-resistant game. It then focused on game protocols and outlined a design that should serve as guidance for implementing a game protocol that uses game validation to provide cheat resistance.

The presented high-level design can be implemented in multiple game types. Note that some corner cases for specific game scenarios were left out due to space constraints and may require additional design effort. The example protocol shows that it is possible to create a highly scalable, cheat-resistant peer-to-peer network that requires little to no server capacity. Once designed and implemented, such a system can be used across multiple games and handed off to players when a game is sunset. This approach significantly reduces operations costs by using player resources instead of the cloud or datacenter while providing similar cheat protection.

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► Cloud for Gaming

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Selection Techniques

► 3D Selection Techniques for Distant Object Interaction in Augmented Reality

Self Narrative

► Preserving the Collective Memory and Re-creating Identity Through Animation

Self-Motion Misperception

► Perceptual Illusions and Distortions in Virtual Reality

Semiotics of Computer Games

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Synonyms

Ludosemiotics

Definition

The expression "semiotic of computer games" can be used both to indicate a specific semiotic-object (the system of meaning articulated and conveyed by digital games) and the discipline that studies it.

Introduction

Semiotics, literally the doctrine of signs, is a discipline focusing on meaning and interpretation. According to a famous definition by Umberto Eco, semiotics deals with *everything that can be used to lie:* if something cannot be used to lie, it cannot also be used to state the truth and, therefore, it cannot be used to say anything at all.

In the last decade, several semioticians have started to choose as a specific field of studies that of computer games. It is a field that, from a semiotic perspective, both intriguing and problematic. On the one hand, it offers interesting new ways of expressing meaning and telling stories, mixing multimedia story-telling with interaction and personalization. On the other hand, it often eludes the tools and methodologies that the discipline has polished when dealing with literature, cinema, or comics.

State of the Art

Any attempt to approach the way in which computer games organize and circulate meaning, therefore, needs a critical reassessment of its tools. For example, in his book on *cybertextuality* Espen

Aarseth criticizes harshly the practice of applying literary theory to *cybertexts* without a revaluation of its concepts (Aarseth 1997: 14). He claims that his early works on labyrinthine texts often faced misunderstanding due to the interference of literary theories. In other words, while he tried to describe the importance of texts with a labyrinthine enunciation (the cybertexts) his audience was focusing on texts with a labyrinthine interpretation (what Umberto Eco calls "open works").

Also for this reason semiotic theories of digital games are often developed in direct dialogue with game studies – more ready to recognize the novelty of the medium.

Some attempts to such a synergy have been already attempted also by game scholars. For example Mäyrä (2008: 19) borrows some terms from the semiotic metalanguage and introduces the term *ludosis*, indented as meaning making through playful action.

Due to the complexity of the discipline and of its metalanguage, however, most of the attempts of combination between semiotic theory and game studies have been attempted by trained semioticians borrowing theories and ideas and integrating them in a mono-disciplinary conceptualization.

Only a few of the "forefathers" of semiotics directly approached games as an object of study. A great number of them, however, used them extensively as a metaphor. Semioticians such as Ferdinand De Saussure, Umberto Eco, Algirdas Greimas, Louis Hjemslev, Émile Benveniste, Boris Egorov, Boris Uspensky, and Claude Levi-Strauss resorted to games in order to explain the inner workings of language, society, and even culture. Among the most commonly mentioned games, chess is the more frequently exploited, even if also playing cards have been used to this end several times. Idone Cassone (2014) summarizes several of these approaches and argues that it is the systemic structure of games that makes them particularly appropriate for such parallelism. Nevertheless, some important semioticians have indeed written fundamental pages about play – above all Juri Lotman (see Thibault 2016) and Algirdas Greimas (1980).

The first attempts to deal with *digital* games are quite recent, but a "semiotic way" to deal with video games has been outlined by several scholars all around the world (to mention few of them: Gabriele Ferri, Mauro Salvador, Agata Meneghelli, Carlos Scolari, Massimo Maietti, Matteo Bittanti, Patrick Coppock, Jack Post, Dario Compagno, Vincenzo Idone Cassone, Joaquìn Siabra-Fraile, Maria Ilia Katsaridou, Simon Levesque, Enzo D'Armenio, Gianmarco Giuliana, etc.).

Semiotic Dimensions of Computer Games

A semiotic approach to play must immediately recognize the twofold nature of this phenomenon that involves at the same time an activity (or process, or enunciation) and an objectual (or "textual") nature (see Salvador 2015). On the one hand, "to play a game" is a verb indicating an action: the engagement of a particular behavior and a specific way of interacting with objects and people. On the other hand, games involve the use and creation of several texts: digital objects and representations, but also the play sessions themselves that can be interpreted (and analyzed) as performances.

The relationship between process and text in games features many interactions. Agata Meneghelli writes that games are a *chain* of texts and practices: game design is a productive practice that creates a text (the video game) and generates a practice (to play it) that brings to light another text (the played game) (Meneghelli 2011: 25).

From this duplicity arise two of the main directions of semiotic analysis of play:

- The first one focuses on play as a *process* involving several semiotic activities: the institution of signs, a selection of saliences (i.e., which ones, of the objects of the world, are relevant or not for the activity), the acquisition of a semiotic *competence* (the knowledge of how to interpret and undertake successfully the activity), and several forms of communication – among them the metacommunication of one's playful intentions (Bateson 1955; Sutton-Smith

1997), direct communication with other players, and the spectacularization of the activity.
- The second direction of analysis focuses on the *textual* nature of play. This approach multiplies the subjects of the semiotic activity, because it encompasses also the work of game designers, i.e., the authors of the "first-level" texts. The players, therefore, would not be seen only as the authors of the *play-text*, but also as the readers of the game. This, obviously, entails a series of semiotic issues about sound narrative, visual communication, literacy and competence, and interpretation and use of the ludic texts.

There is, however, a third aspect of play that is semiotically extremely relevant: its cultural dimension. Themes such as the ludicization of culture, the social stigma that often accompanies digital games, the relationship between games and pop culture or art are also at the center of semiotic analyses.

Cross-References

▶ Narrative Design
▶ Storytelling in Virtual Reality

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Sensory Disabilities

▶ Making Virtual Reality (VR) Accessible for People with Disabilities

Sensory Disability

▶ Computer Games for People with Disability

Sequence Breaking

▶ Speedrunning in Video Games

Serious Games

▶ Augmented and Gamified Lives
▶ Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay
▶ Gamification in Crowdsourcing Applications
▶ Immersive Virtual Reality Serious Games
▶ Information Presentation Methods in Virtual Reality
▶ MEEGA+, Systematic Model to Evaluate Educational Games
▶ Nursing Education Through Virtual Reality: Bridging the Gap
▶ Political Game Design
▶ Public Health Education via Computer Games
▶ ROP-Skill System: Model in Serious Games for Universities
▶ Strategies for Design and Development of Serious Games: Indian Perspective
▶ Timed Automata for Video Games and Interaction
▶ Transformational Games
▶ Virtual Reality Proton Beam Therapy Unit: Case Study on the Development

Serious Online Games for Engaged Learning Through Flow

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Synonyms

Game-Based Learning (GBL); SG: Serious Game(s); SOG: Serious Online Game(s)

Definition

SGs are video games, which are mental competitions played with a computer in accordance with specific rules that use entertainment to enhance education, corporate training, health, public policy, and strategic communication (Connolly et al. 2012).

SOGs are online community games, which are concerned with affective learning outcomes to change not only perceptions, but also behaviors and attitudes through awareness raising on various policy issues (Fishbein and Ajzen 1975). SOGs may even aim at transforming the participants' mindset along with emotions so that they become more open-minded, humanitarian, and self-reflective primarily in their own environment, such as workplace, school, or household.

Introduction

Online games have been gaining increasing attention lately since computer technology has provided new opportunities for mobile learning. Playing online games that are embedded in social media is more than an isolated mental contest against a computer; it is both an interactive experience of a second self and a shared group action. Getting immediate feedback can induce high levels of engagement in such games, as well as a feeling of control and development. These games provide the highest degree of concentration simultaneously with social networking.

In "positive psychology," M. Csikszentmihalyi (1991) has found out that a large part of happiness is achieved by voluntary activities – half of which is determined by flow. He had found that the more often people report-reading books, the more flow experiences they claimed to have, whereas the opposite trend was found for watching television passively. Csikszentmihalyi studied people's inner states while pursuing activities that appear to contain intrinsic rewards, such as games, dance, sports, and music. He highlighted an experience of "flow state," which is the merging of action and awareness through total immersion in an activity that is challenging yet closely matched to one's skills. His work has been embraced by various fields during the Covid-19 pandemic, particularly after he passed away, since intrinsic motivation for learning and creativity has become critical for distance learning and working in isolation. By employing online formats, serious games are recognized by communities as an alternative means to promote engagement and learning. Consequently, this new venue has enhanced an optimal experience of flow along with a heightened interest in creativity, innovation, collaborative discovery, and learning, if used properly.

In this article, how "positive psychology" can contribute to the design as well as the role of positive emotions and preferences in SOG by focusing on connected and participatory gaming, that is, combining instructionist with constructionist perspectives is addressed (Isbister 2016). While the first is on having learners play conventional educational games, the latter is on having them make their own games, or co-designing together with experts, i.e., designers and psychologists.

According to the theory of flow, along with the role of positive emotions such as interest, well-being, joy, love, and empathy broaden people's momentary thought-action repertoires and

enhance learning and coping ability; as a consequence, people become more resourceful, curious, creative, and understanding (Alexiou et al. 2012). Hildmann and Hildmann (2009) have established models for GBL in classrooms. Integrating pedagogy into SOG experiences to GBL, and SOG community may fill the gaps in theory, design, and practise; such an ambitious interdisciplinary research will pave the way toward a collaborative online learning community in near future.

Overview of the Literature

The State of Flow Model

Mihaly Csikszentmihalyi (1991) outlines that the most successful websites are the ones that offer interactive experiences, not simply content. The state of flow can be created online if the following essential conditions are combined: user motivation, user telepresence, and interactivity of the web-based application. In defining "the optimal autotelic experience," he highlighted the below major factors that are applicable to digital games:

1. A challenging activity requiring skill and a dynamic balance between the two.
2. A merging of action and awareness.
3. Clear proximal goals and norms.
4. Direct, unambiguous, and immediate feedback.
5. Focused concentration on the task at hand in the present.
6. A sense of control of one's activities.
7. A loss of self-consciousness.
8. An altered sense of time, that is, loss of time awareness or time acceleration The last two components lead to full immersion and a deep state of flow.
9. Finally to: "the optimal autotelic experience" (Csikszentmihalyi 2014).

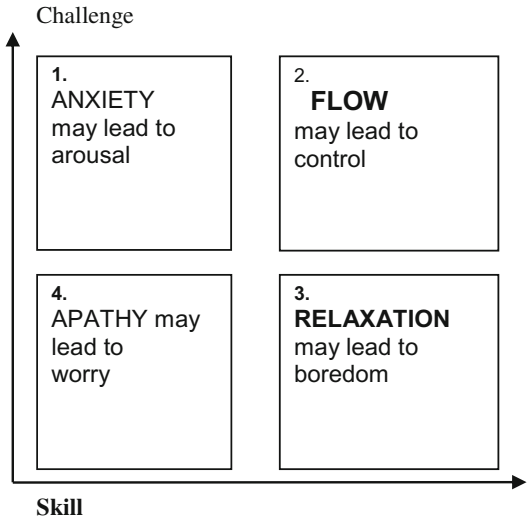
The psychological basis of this developmental process is the inducement and the use of the "state of flow." This concept is used by psychologists to describe a mental state in which the attention is highly concentrated on a specific process, the environmental information is screened out, and the person experiences a harmonious flow of its present experience (Csikszentmihalyi 1991). The state of flow is known to create a state of well-being as well as an increased perception and learning capacity.

Csikszentmihalyi initially used a simple flow questionnaire (FQ); then used the experience sampling methodology (ESM) with his flow theory to be able to analyze the balance of experiences in the following four channels with four alternative edges leading to various combinations of skill and challenge levels. ESM has been used to investigate what the participants experience in solitude through self-reporting techniques. For instance, each respondent reports their happiness levels eight times each day for a week via signals by an electronic pager. It adds up to 40 moments on a seven-point Likert scale ranging from very sad to very happy (Csikszentmihalyi 1997). That way, the flow state of happiness is operationalized and measured.

For any player to attain flow in a game or any activity, a balance needs to be achieved between the external complexity of the system or game program and the internal model a user/player develops of that particular program. A player attains a more accurate internal model of system through learning and virtual experience by trial and error (Csikszentmihalyi 1991). The four channels with respect to different levels of competence and challenges are shown on the next page with Fig. 1.

- Capability $<$ Difficulty (enter)
- Capability $=$ Difficulty (flow)
- Capability $>$ Difficulty (exit)

As can be seen from above, there are often three possible simplified scenarios of the interaction between an Internet user and an online game. When the capability of the player is lower than the level of difficulty of the game, the player will experience frustration and will abandon the game with a negative feeling. If the capability of



Serious Online Games for Engaged Learning Through Flow, Fig. 1 The inducement of the state of flow online. Motivation or pleasant frustration (discomfort) vs. boredom, if not balanced. Should I stay or should I go?

the player is higher than the level of difficulty proposed by the game, a feeling of boredom is likely to result, having as a direct effect the exit of the player from the SOG environment.

Although this quadrant model of flow is simplistic (Moneta 2012), still new empirical research venues are possible to test this general theory. Likewise, there are numerous serious academic games based on flow principles; however, FLIGBY (an online simulation game with an acronym for *FLow Is Good Business for You*) stands out as a serious game that takes all stakeholders into account, while focusing on flow experience. Moreover, FLIGBY is an ambitious gamification of flow-based leadership development simulation process that can be used both at workplace and at school.

Professor Csikszentmihalyi himself has been involved in the creation of FLIGBY to apply the three aspects of SOGs: flow/learning, technology/simulation, and fun/game. In his flow theory, Csikszentmihalyi (2003) highlights the importance of having a sufficient level of challenge and discomfort is necessary for learning and development, since one cannot grow and become humane unless confronted with ethical dilemmas to choose and draw lessons from the intended and unintended consequences of the actions.

By extending his flow theory into leadership, both learning and teaching of flow-compatible leadership values, skills, and practises through blended learning pedagogy in "flipped classroom," where lecture followed by homework and theory followed by practise are reversed, focus is on action of both individuals and groups in school. Likewise, at the workplace, benefits for individual employees lead to benefits for the whole organization. The intended purpose of this game is to help individual leaders/managers and organizations to create a flow-friendly workplace.

Originally developed as a training tool for managers, FLIGBY lets players try their hand at managing a Californian winery during 10 hours of simulation. Participants receive immediate feedback from a virtual coach named Mr. Fligby; they also get evaluative reports showing their ratings with respect to 29 leadership skills. These 29 skills as a competency system with 4 flow skills (i.e., Immediate Feedback, Balancing Skill, Timely Decision-making, and Strategic Thinking) serve as a useful tool for strategic human resource management (Marer et al. 2012).

Multiple feedbacks during (de)briefings not only strengthen an understanding and tolerance toward alternative perspectives, but also teaches empathy with others. Task- and relation-based satisfaction improves performance and commitment at work. A possible fruitful research question will be to trace the four flow-leadership skills across national cultures and determine whether they are universal or not. (Buzady 2017). Further, the quest for altruism versus non-altruism model for behavior may be tested against different cultural contexts.

Discussion and Conclusion

On the whole, systematic evaluation is an essential part of SOG, which demands an interdisciplinary perspective with a broad stakeholder

responsiveness. For this reason, research and application landscapes need to change with respect to the needs of individuals and communities simultaneously. The point of this interactive process is to make people realize their potential as individuals who contribute themselves to the overall needs of the community in the model of flow as in FLIGBY. In essence, this is the point of a communal sense of living with sharing and caring – realizing one's potential and limits as an autonomous self, and then contributing this selfhood to the community of which they are a part. The main philosophical aspect of Csikszentmihalyi's theory of flow is meaning, which is at the heart of well-being, is found through the delicate balance between the self and community; to achieve ultimate goals is not possible if one of them is totally ignored. (Csikszentmihalyi 2013). The state of flow is half of the story concerning well-being, since the personal traits along with cultural contexts have impact on happiness.

SOGs with their transformative powers may aim at raising awareness on many social issues through collaboration in the coming gamer generation. However, it has been claimed that the possibility of "cyber-activism" of alternate reality games on human suffering and the rights of distant others may pave the way to "false-activity" or "ethical-amnesia" due to compassion fatigue, rather than forging an online trustworthy community (Oliver 2010). Critical perspectives emphasize the dystopian assumptions of unconscious desires, immediate gratifications, and escapist or mindless attitudes in their reactions toward SOGs and cyberspace; therefore, the stakeholders are claimed to be at the risk of being consumed by digital games (Pelletier 2010). Other scholars have an optimist perspective since they rely on a utopian vision; therefore, they highlight the liberating potential of Internet and cyberspace. FLIGBY is based on idealist and hopeful premises of a bright future teaching trust, empathy, and understanding along with creativity and improvement of leadership.

Finally, the flow theory of Czicksentmihalyi, however, reveals the fact that it all depends on how the theoretical framework is linked to the practise through the multifaceted nature of SOGs. How SOGs are designed, implemented, and analyzed have to be considered thoroughly with user tests before their final evaluation. Well-defined and well-designed SOGs can offer an antidote to our concerns about the de-sensitizing effect of information overflow, interweaving of work, technology, home life, and leisure. In SOGs, making difficult choices and coping with their consequences at different levels of analyses, active and optimal learning might be enhanced.

Ordinary life with its issues and incompatible trade-offs is progressively becoming the imaginary world of SGs and SOGs; for instance, *Fligby, Second Life,* and *SimCity*. Through the convergence of several technologies and social forces accelerated by Covid-19, Metaverse is the latest simulated extension of the real world. One can still hope for and imagine a future SOG community, whereby nurturing and loving experiences even in intimidating landscapes with crises may bring people together, rather than apart. Although scientific and artistic curiosity will continue to be a potential usage of SOGs that go beyond the representation of reality, they are most convenient at schools and workplaces for learning real and mundane issues.

While Csikszentmihalyi's ideas come from a psychological foundation, they aid serious game designers and evaluators to realize the significance of an emotional connection when creating a new game as a product. Researchers will increasingly concentrate on how to create games that make people happy at work, school, and home since positive emotions and attitudes enable and enhance productivity and success. His theory of flow and ESM method gives the information and game community food for thought with numerous significant theoretical and practical implications.

In sum, the SOG designers need to be aware of how relevant stakeholders connect and relate themselves within a particular conceptual model. The flow concept is being adopted to different

contexts and contents; therefore, systematic reviews, meta-analysis studies, and evaluations are important for new SOGs. Further, co-designing with experts is suggested here so that the primary connection between flow, design, and evaluation cycle may be continually, if not continuously reread with the feedbacks of all stakeholders. Community and individual norms and standards are relative to each other and connected with each other in the flow model. SOGs in future may only be improved in terms of how they are designed as a process (gamification), by whom and for whom they are designed (stakeholders), and for what purpose they are defined and evaluated (goal and norm). (Csikszentmihalyi 2003).

The opportunity to use the power of SOG to assist psychological interventions will continue; however, its role to enhance education and management/leadership is conceivable in near future. The challenge is the difficulty of unlearning, relearning (resetting), and learning in a different format due to "the creative destruction of new technologies" like the Metaverse ecosystem. "The perennial gale of creative destruction" is an essential fact of capitalism according to Schumpeter (1942), since new production/service units and processes replace outdated ones for optimization. The seeds of this new ecosystem are being planted; whether one or many metaverse platforms will unfold is yet to be seen.

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► Immersive Virtual Reality Serious Games

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SG: Serious Game(s)

► Serious Online Games for Engaged Learning Through Flow

Shadow Shooter: All-Around Game with e-Yumi 3D

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Synonyms

Augmented reality; Human-computer interaction; Human-computer interface; Mixed reality

Definition

I introduce here "Shadow Shooter," AR shooter game. It uses a bow interface system called "e-Yumi 3D" and real physical interactive content that changes a 360° all-around view in a room into a virtual game space.

Introduction

In this entry, I will introduce Shadow Shooter and e-Yumi 3D. The development of computer games and devices associated with them (e.g., Kinect and Wii) has continued to advance, which has enabled players to combine their physical capabilities and motions with games and sports in a virtual world. Additionally, various studies have been done that focus on playing virtual games or sports using a particular device. However, such devices and games can only use gestures or basic motions of games and sports, and it is difficult for players to achieve a strong sense of reality.

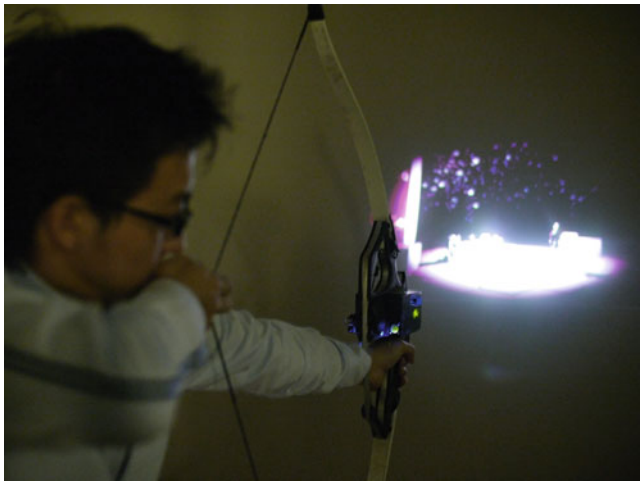
Some studies have used components of real sports equipment as devices in order to improve the user experience (Geiger et al. 2013; Owetschkin et al. 2013; Yasumoto 2013). Geiger's Virtual Archery (Geiger et al. 2013) and Owetschkin's Mobile Virtual Archery (Owetschkin et al. 2013) use a real bow as an interactive device to create positive user experiences. However, they respectively require a large projection screen and a smartphone screen as a display, so users are likely to fail to recognize real-scale distances between themselves and the shooting targets in a virtual world. The Light Shooter (Yasumoto 2013), my previous interactive content, also uses a real bow device – the Electric Bow Interface (Yasumoto and Ohta 2013). This device recognizes all directions that arrows are shot in and projects real-scale targets, which are animals and humans with biological motion. However, it displays directions only with a standing projector; thus, users cannot get a strong sense of reality all around them.

Against this background, I constructed Shadow Shooter that uses the e-Yumi 3D interface and real physical interactive content that changes a 360° all-around view in a room into a virtual game space (Fig. 1). This system was constructed by developing my previous interactive Light Shooter content. Shadow Shooter expands the virtual game space to all the walls in a room just as in Jones' RoomAlive (Jones et al. 2014); however, it does not require large-scale equipment such as multiple projectors. It only requires the e-Yumi 3D device, which consists of real bow components added to Willis's interface with a mobile projector (Willis et al. 2013). In this paper, I describe the construction of e-Yumi 3D and the concept of Shadow Shooter.

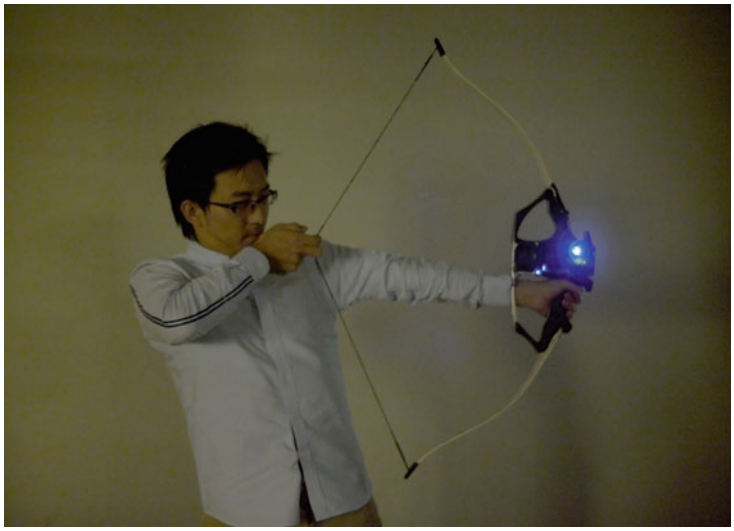
State of the Art Work

e-Yumi 3D Hardware

I introduce my e-Yumi 3D system. As shown in Fig. 2, e-Yumi 3D is based on an real archery bow and also includes a mobile laser projector, a 9-axis sensor (3-axis accelerometer, 3-axis digital compass, 3-axis jyro sensor), two strain gauges, Arduino Nano and its control board, a Windows PC, a speaker, and a battery. The 9-axis sensor is connected to the PC via a USB and is used to detect the direction of bow. The degree that e-Yumi 3D's string is drawn is correctly calculated from parameters of the strain gauge with Arduino Nano and its control board. Additionally, the shooting of the e-Yumi 3D can be detected from the strain gauges on the bow's upper limb.



Shadow Shooter: All-Around Game with e-Yumi 3D, Fig. 1 Depiction of Shadow Shooter in use



Shadow Shooter: All-Around Game with e-Yumi 3D, Fig. 2 e-Yumi 3D

Therefore, the arrow is virtual, but its track seems to be real.

Game Engines

I use Unity for this Shadow Shooter as a game engine and the sensor server software. I use two kinds of sensors, 9-axis sensor and strain gauge. Strain gauge connects Arduino Nano and Unity connects Arduino Nano via USB. However, 9-axis sensor connects a Windows PC directly. Because Unity cannot recognize the DLL for 9-axis sensor, this sensor server software connects 9-axis sensor and gets information once. Next, the sensor server software connects Unity via Win Socks and send information.

Graphics Expression

In this game, players cannot watch the figure of enemies. In the screen, there are a lot of dots. Some dots are moving randomly, and some dots are moving biologically. I use biological motion for enemies' animation like The Light Shooter. Additionally, there are shadows. Players cannot watch the enemy directly, but if player shoots the

arrows, they illuminate the shadow of enemies, so players can recognize them as shown in Fig. 3.

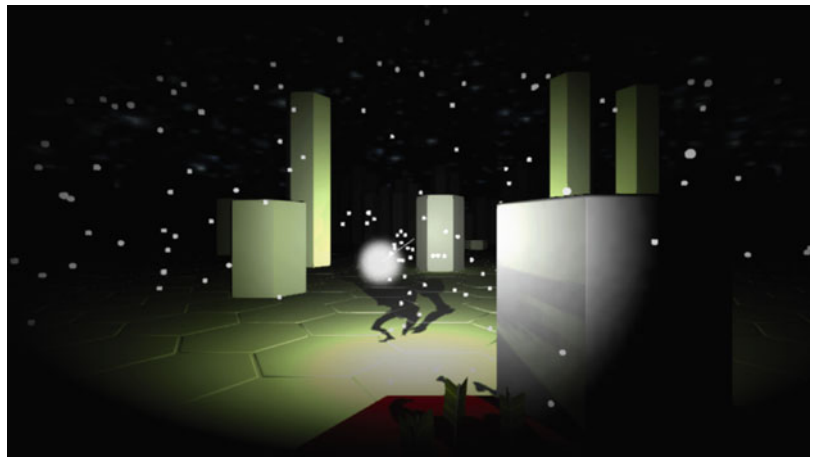
I recommend players play Shadow Shooter in the dark room. Players cannot see anything but if players aim the walls, ceiling, or floor of the room with the e-Yumi 3D, images of game are shown with a flashlight in hand in the darkness. This Shadow Shooter is like horror shooting game.

Overview

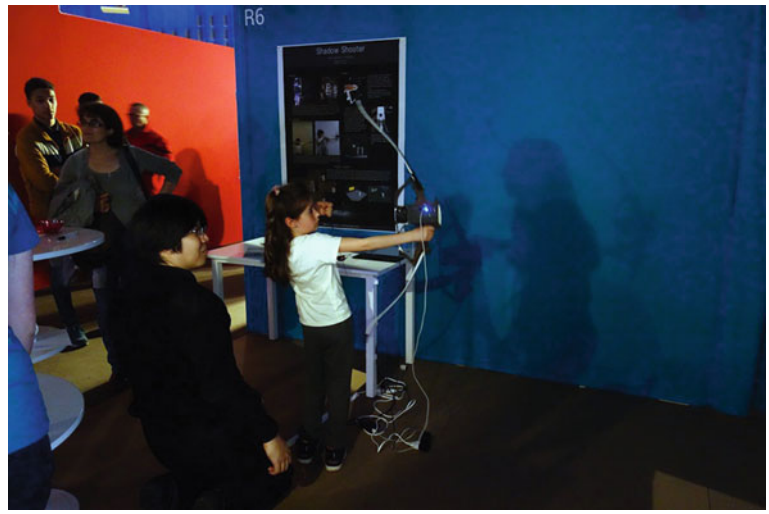
Shadow Shooter needs the e-Yumi 3D and dark room. In the room, players equip e-Yumi 3D and aim anywhere, e-Yumi 3D detects the direction of the bow with 9-axis sensors in it, and projects the image of the same direction of the virtual world of Shadow Shooter with a mobile laser projector in it. Players can play the 360° horror shooting game as an immersive game like using HMD, but this system does not need HMD.

Experiments and Show Cases

I exhibited this Shadow Shooter as playable in several countries in the world , CEDEC 2014, Laval Virtual Revolution 2015 (Fig. 4), and Tokyo Game Show 2015.



Shadow Shooter: All-Around Game with e-Yumi 3D, Fig. 3 Game image of Shadow Shooter



Shadow Shooter: All-Around Game with e-Yumi 3D, Fig. 4 Exhibition in Laval Virtual 2015

Cross-References

- ▶ 3D Room Layout System Using IEC (Interactive Evaluational Computation)
- ▶ Accessibility of Virtual Reality for Persons with Disabilities
- ▶ Decoupling Game Tool GUIs from Core Editing Operations
- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Interactive Virtual Reality Navigation using Cave Automatic Virtual Environment Technology

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Shape Deformation Computer Imaging

- ▶ Shape Deformation Models

Shape Deformation Curves

- ▶ Shape Deformation Models

Shape Deformation Models

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Synonyms

Shape deformation computer imaging; Shape deformation curves; Shape deformation polygons; Shape deformation surfaces

Definition

Shape deformation models have occupied a prominent place in computer graphics and image processing. They possess superior geometric properties of flexible nature which make them an ideal candidate for several applications in graphics and imaging industry. In this article, some basic properties of shape deformation models are presented. These properties are highlighted though examples. An industry application with respect to topology driven structures through deformation with 3D shape correspondence of varying nature further highlights the strength of these models.

Introduction

The deformation of shapes corresponds as a basic problem in geometric modeling (González Hidalgo et al. 2013). Several methods have been developed to address rigid alignments, isometric shape articulations, part stretching nonrigid shape deformations, etc. Considering the inherent matching shapes dissimilarity, the search for correspondence becomes complex with respect to formulation of the problem computation cost. In

order to deal with shapes varying in structure as well as geometry, the current techniques are basically data or knowledge based. They make use of various supervised learning or unsupervised co-analysis for collections of shape. In terms of design, these techniques give coarse as well as discrete correspondences which leaves structural discrepancies considering matched parts or their ensembles unsettled. Some examples worth mentioning are available in (Chaudhuri 2018).

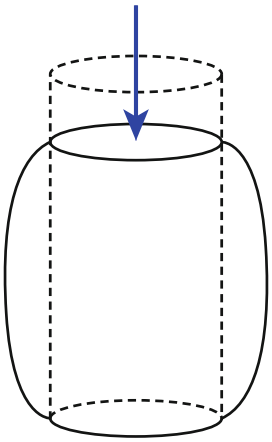
The deformation process can be represented through hierarchy modeling which effectively represents object geometrically. Though this simple graphical primitives along with operators are combined together towards the formation of complicated objects. In the hierarchy of leaf nodes, there are hardware commands from where vectors are drawn, individual pixels' colors change, and operations are performed on list of segmented polygons. With respect to proper algorithms, the users have strong intuitive feeling for manipulation of results. They can also think for every operation and can structure the objects they are looking for. These deformations enforce the user to consider an object from special topology that can be bent, twisted, tapered, compressed, expanded, or transformed towards a final construct. They have highly intuitive nature. They have visualized operations which simulate some kind of manufacturing processes towards objects' fabrication. These deformations have also been considered towards traditional CAD/CAM modeling as well as surface patches. This decreases the data storage requirements, which simulate flexible objects geometrically. This makes it possible towards accurate modeling of physical properties for various elastic materials considering several partial differential equations. However, simple mathematical deformation techniques also exist. These simple techniques have reduced requirements in terms of computation. They model objects effectively.

A fair amount of work has been done on matching discrete structures, deformation driven correspondence, structure aware deformation, topology matching and blending, as well as co-analysis. This is in lines with deformations of shapes where the 3D geometrical structures are actively used. With this motivation, in this article we present some basic concepts related to shape deformation which are supported with illustrative examples. An industry application revolving around a deformation driven technique considering varying topology with shape correspondence in 3D is highlighted. This article is structured as follows. In proceeding section, the shape deformations overview is given. This is followed by an industry application in shape deformations. Finally, the conclusions are given.

Shape Deformations: Overview

The shape deformation can be defined as any object's shape change which happens because of a force applied externally or temperature change. For shape change of an object, the deformation energy is transferred through work done. For temperature change, the deformation energy is transferred through heat. The first instance is attributed towards tensile and compressive forces as well as shear, bending, or torsion. The second instance is determined through temperature and is the structural defects mobility where the movement is thermally activated. The deformation also results from strain. The deformation is also associated with stability of an elastic material through incremental deformations. It is based on superposed small deformation considering an equilibrium solution. When deformation takes place, the internal forces of inter-molecular nature take place that opposes the external forces. If external force is not adequate, the forces are enough towards fully resisting said force. This also allows objects towards new equilibrium and return to actual state as the load withdraws. The greater external forces will go towards object's full deformation as well as its structural distortion.

Figure 1 shows that compressive loading which is shown by arrow causes cylinder deformation such that original shape shown by broken lines is deformed considering sides which are bulging. The sides bulge as material because it is



Shape Deformation Models, Fig. 1 The object deforms because of stress (it shortens, and expansion takes place in outward direction)

not strong enough to break or support any load. This results in forcing the material out laterally. The internal forces at right angles to deformation resists applied load. For negligible deformations, the object may be considered as rigid body.

We now present the basic mathematical formulations for shape deformations which are specified through global and local deformations. The global 3D solid deformation is mathematical function $\overline{H}$ that changes global coordinates towards points specified in space. The points for undeformed and deformed solids have been specified through $\overline{a}$ and $\overline{A}$, respectively. This is represented as:

$$\overline{A} = \overline{H}(\overline{a}) \tag{1}$$

Let us consider a_1, a_2, and a_3 as the components of 3D vector $\overline{a}$ in three directions.

The local deformation changes tangent space for solid. The differential vectors for solid's substance are circulated and skewed accordingly. There is an integration of these vectors considering the position globally.

There are separate chain links considering differential vectors that may stretch as well as rotate. The deformation's local specification is given by matrix function which may be circulating as well as skewing. The end link's position considering chain is vector sum for previous links and is discussed here.

Considering the modeling aspect, the two important vectors are tangent as well as normal. The first vector is used towards delineation and construction of local geometry. The latter is used towards orientation of surface as well as information for lighting. There is a transformation for the tangent as well as normal vectors from the undeformed to the deformed surface. The manipulations towards rules of transformation consider single multiplication with respect to jacobian matrix $\overline{\overline{JM}}$ for transformation function $\overline{H}$. The jacobian matrix $\overline{\overline{JM}}$ considering transformation function for Eq. (1) is function of $\overline{a}$ and is computed through partial derivatives for $\overline{H}$ with a_i; $i = 1, 2, 3$ such that:

$$\overline{\overline{JM}}_i(\overline{a}) = \frac{\partial \overline{H}(\overline{a})}{\partial a_i} \tag{2}$$

As such, ith column for $\overline{\overline{JM}}$ is achieved through partial derivative for $\overline{H}(\overline{a})$ considering a_i. The object's surface is represented through parametric function for variables p and q such that:

$$\overline{a} = \overline{a}(p, q) \tag{3}$$

Any tangent vector considering the surface is reached through linear combinations of partial derivatives for $\overline{a}$ considering p and q. The normal vector direction can be obtained through cross product for linearly independent tangent vectors considering surface.

The transformation rule for tangent vector is restated in terms of a chain rule. As a result of this, new vector derivative is jacobian matrix times the previous derivative such that:

$$\frac{\partial \overline{A}}{\partial p} = \overline{\overline{JM}} \frac{\partial \overline{a}}{\partial p} \tag{4}$$

In component form, the above equation can be written as:

$$A_{i,p} = \sum_{j=1}^{3} JM_{ij} a_{j,p} \tag{5}$$

The transformation rule for normal vector requires jacobian matrix inverse transpose such that:

$$\overline{\boldsymbol{n}}^{(A)} = \det JM\overline{\overline{JM}}^{-1T}\overline{\boldsymbol{n}}^{(x)} \quad (6)$$

Since only normal vector's direction is significant, it is not required to calculate determinant's value. The jacobian's determinant looks towards local volume ratio for each transformation point considering deformed as well as undeformed regions. Scaling is one of the simple examples of shape deformation (https://abaqus-docs.mit.edu/2017/English/SIMACAECAERefMap/simacae-t-customdeffactorframe.htm). Other notable examples include global tapering along any axis, global axial twists, global linear bends along any axis (https://abaqus-docs.mit.edu/2017/English/SIMACAEGSARefMap/simagsa-t-displayingandcustomizingadeformedshapeplot.htm), etc. We present few of these examples here.

Global Tapering Along Any Axis

The tapering operation is identical to scaling. It has been applied towards many flexible objects. It is achieved by differentially changing two global components' length without changing third component's length. The process is represented through piecewise linear function which decreases as the other axis increases. Figure 2 represents tapering of any ribbon.

Global Axial Twists

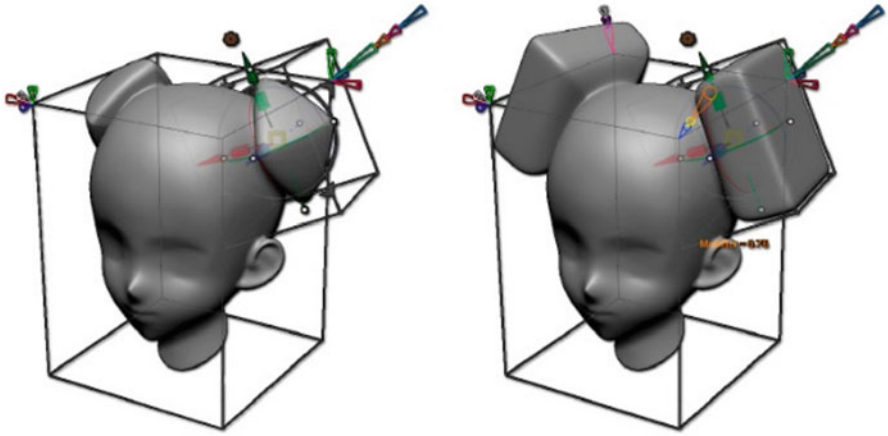
The global axial twists basically simulate an object's global twist. The twist is approximated through rotation achieved differentially. It draws analogy from the global basis vectors' differential scaling. Here rotation is performed in terms of global basis vectors' pair which is height's function where third global basis vector is not altered. This deformation process is enforced through twisting a cards' deck with every card being rotated somewhat more than the card below it. Figures 3, 4, 5, and 6 represent global axial twists process for several objects of interest such as ribbon's progressive twist, two primitives' progressive twist, tapered primitive twist, and twisted offset primitive tapering.

Global Linear Bends Along Any Axis

The global linear bends along any axis mimics the bending simulation process. It is basically represented through bend of isotropic nature considering centerline parallel with respect to any specified axis. During bending process, centerline stretch does not change. The angle at bending is always constant considering extremities. However, all the changes take place linearly considering central part. Considering region at bent, rate of bending is kept fixed, and differential basis vectors are rotated and translated with respect to the third local basis vector. The deformation comprises of rigid body rotation as well as translation outside bent region. Here range of bending deformation is controlled through specified axis. Figures 7, 8, 9, 10, 11, and 12 represent global linear bends along any axis for several objects of interest such as region's progressive bending, region's progressive change in bending range, moebius band produced through twist and bend, tapered primitive with bents and twists, bent and

Shape Deformation Models, Fig. 2 A ribbon's tapering progressively

Shape Deformation Models, Fig. 3 A ribbon's progressive twist



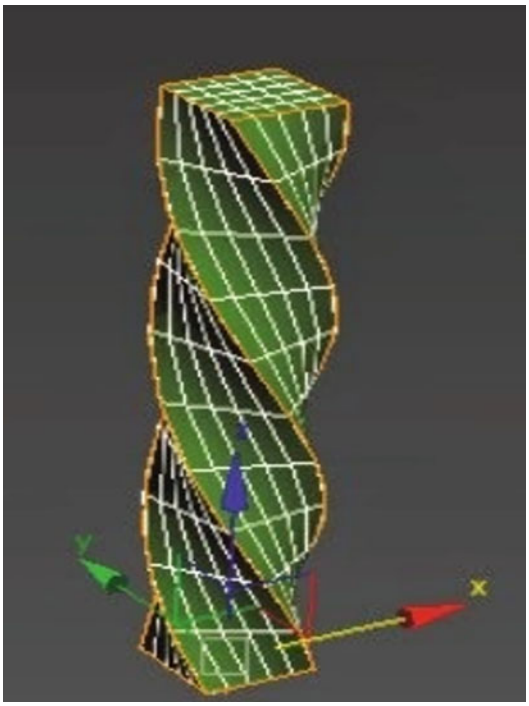
Shape Deformation Models, Fig. 4 The two primitives' progressive twist

Shape Deformation Models, Fig. 5 The tapered primitive twist

twisted primitive and chair's model considering six primitives with seven bends.

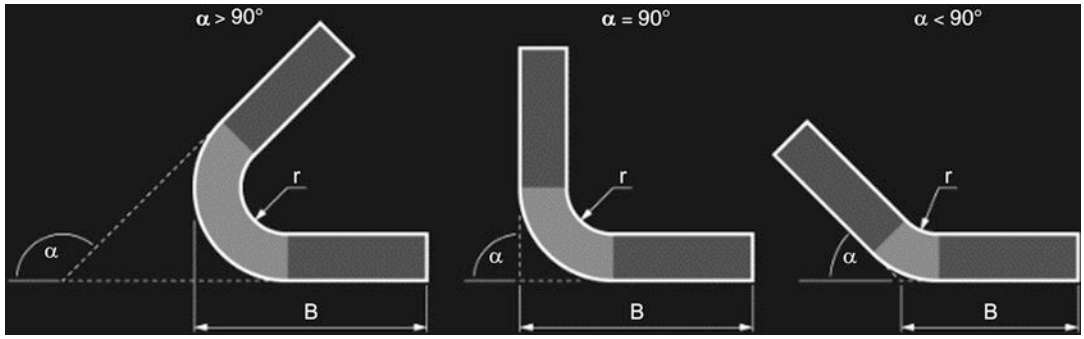
Now we discuss the process for generating more generalized shapes. In this direction, it converts local representations towards global representations with respect to shape deformations. The Jacobian matrix is generally known beforehand as a function of its parameters. However, the expression with closed form considering deformation function is not specified. The basic method revolves around the following steps:

(a) The undeformed input shape's conversion into its tangent vectors considering differentiation
(b) The tangent vectors' transformation through tangent transformation considering tangent vectors with respect to object deformed
(c) The integration of new tangent vectors towards new position vectors for deformed curve, surface, or solid spaces

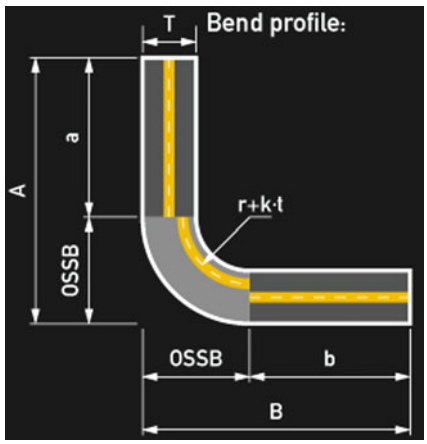


Shape Deformation Models, Fig. 6 The twisted offset primitive tapering

The local towards global operations changes local tangent vectors and Jacobian matrix in terms of position vectors globally. The space's absolute position for deformed object is specified within arbitrary constant vector integration. This gives complete deformation description which can



Shape Deformation Models, Fig. 7 A region's progressive bending



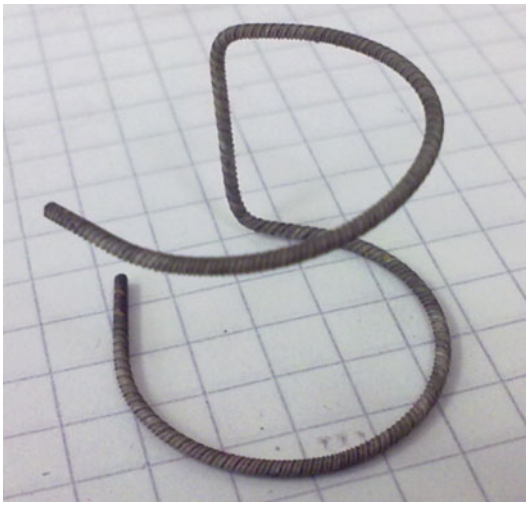
Shape Deformation Models, Fig. 8 The bending range's progressive change for a region

Shape Deformation Models, Fig. 9 The mobius band that is developed through bends and twists

be directly coupled towards output considering elasticity equations or finite element analysis for entities of deformable nature describing general shapes' composition. To further augment this discussion, two significant applications include space curves as well as 3D surfaces and solids transformations available in (Chaudhuri 2018).

Another application of shape deformation worth mentioning is available in rendering (Chaudhuri 2018). To achieve the control points and normal vectors set for which the surface patches with polygons or splines are developed, the surface deformed is sampled parametrically. Considering proper sampling, patches can deform the target object in more detailed manner when surface curvature is high and lesser detail where there is flatter surface. With the parametric values for raw grid, the object is at first sampled. The raw parametric surface's sampling is refined through vector criteria normally which is compute considering rule of transformation. There is recursive subdivision for adjacent normal vectors where divergence is large. The dot products that are wide enough from unity indicate that large recursive detail is required for that part. Therefore, patch-based methods such as depth buffer as well as scan line encoding schemes are good. There is linearity in these algorithms with respect to total surface area as well as number of patches. The direct subdivision approach is not suitable towards ray tracing as the total number of operations becomes quadratic considering number of ray comparisons and objects. In order to reduce the number of objects, the incident ray is intersected with deformed primitives analytically. The inverse deformations can also be used

Shape Deformation Models, Fig. 10 The tapered primitive with bents and twists



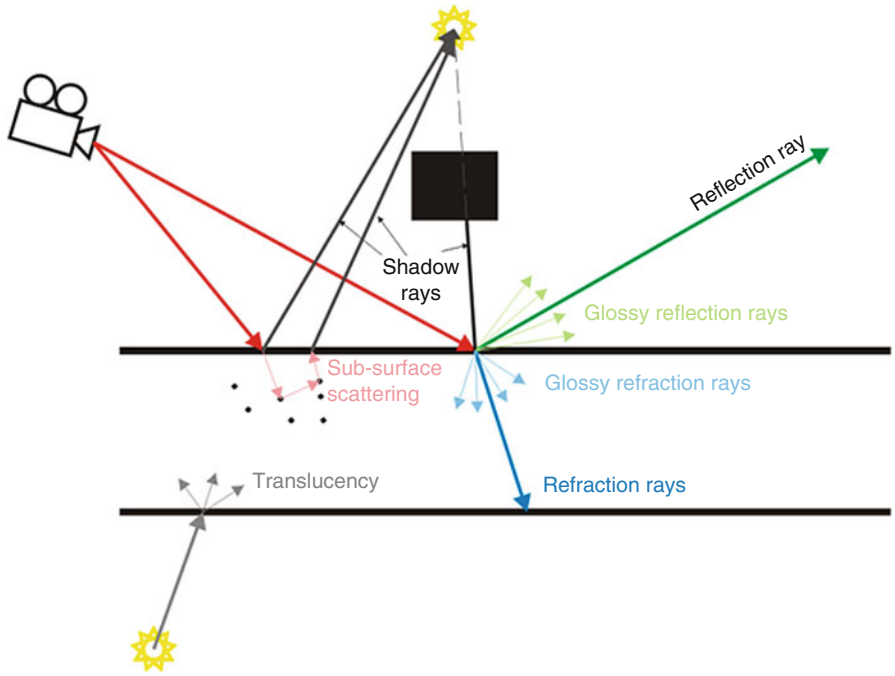
Shape Deformation Models, Fig. 11 A bent and twisted primitive

to undeform primitives as well as tracing along deformed rays. Figures 13 and 14 represent the primitive of deformed nature in undeformed space and undeformed primitive with respect to undeformed coordinate system considering ray's path. This reduces dimensionality for parameter search considering three towards one which indicates considerable benefits in terms of computational complexity.

Shape Deformation Models, Fig. 12 The model of chair considering six primitives with seven bends

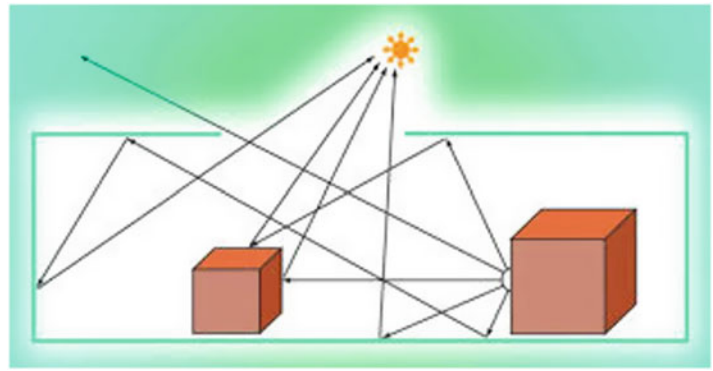
Industry Application

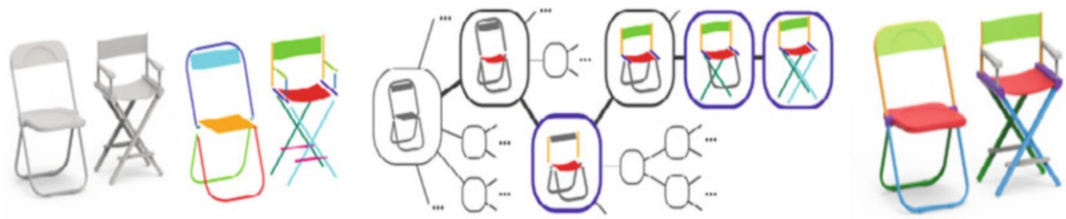
In this section, a novel industry application revolving around a topology driven through deformation with 3D shape correspondence of varying nature. The 3D geometry enforces shape deformation algorithm to consider 3D shapes as inputs (Alhashim et al. 2015). This allows more generalization for the deformation models. The input shapes are upright oriented and segmented as significant parts adhering to all the symmetries. The shapes are represented through shape's topology encoding considering parts' medial abstractions and structural relations with respect to various connectives and symmetries. A combinatorial tree may be traversed to reach part correspondence with pruning of priority nature. The priority is enforced through self-distortion energy. The evaluation is performed considering deformation from one shape to another under previously matched parts' constraints. This produces piecewise continuous part-to-part mapping. Figure 15 highlights a typical correspondence approach (Alhashim



Shape Deformation Models, Fig. 13 The primitive of deformed nature in undeformed space

Shape Deformation Models, Fig. 14 The undeformed primitive with respect to undeformed coordinate system considering the ray's path





Shape Deformation Models, Fig. 15 A typical correspondence approach (with target shapes and curve-sheet abstractions on extreme left, the search tree in middle part, and final correspondence result on extreme right)

et al. 2015). For shapes having large number of parts, course towards fine approach is adopted when search is performed for optimum correspondence. The correspondence may be from all the source parts to some target parts, but the reverse is not valid. Therefore, several source parts can be matched towards identical target part. However, there might be unmatching for certain target parts. The deformation energy determines which source to target designation yields the best solution.

This deformation model considers geometric as well as topological operations like part split, duplication, merging, etc. which leads towards fine-grained and piecewise results. The key aspect here is the deformation energy which affects geometric distortion. It also encourages preservation of structures as well as allows changes in topology. It accomplishes this by connecting shape parts through structural rods that behave in a similar manner as virtual springs. It allows encoding for energies coming from geometric, structural, and topological shapes. The optimal shape correspondence is reached considering the pruned beam search.

This process can be sketched as consisting of four steps, viz., initial segmentation, graphical structured representation, self-distortion energy, and correspondence search. The initial segmentation looks towards computation of fine-grained correspondence parts. The graphical structured representation defines the shape of segments as significant concrete structures achieved through various methods. The self-distortion energy is measured considering shape of the source which allows several shape distortions. The correspondence search allows one-to-one as well as one-to-many part correspondences. Figure 16 shows an array of fine-grained part correspondences calculated using this method.

Conclusion

In this article, we have presented some of the important conceptual aspects related to shape deformation models. The shape deformations find immense applications in computer graphics and image processing. Some of the basic properties of shape deformations are initially highlighted followed by illustrative examples. An industry application considering topology driven structures through deformation with 3D shape correspondence of varying nature justifies the significance of the shape deformation models.

Shape Deformation Models, Fig. 16 The array of fine-grained part correspondences calculated using this method (Considering each pair of input 3D models, the best-rated correspondence is shown; The matching parts have identical color and others non-matching parts are in gray)

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Shape Deformation Polygons

▶ Shape Deformation Models

Shape Deformation Surfaces

▶ Shape Deformation Models

Shared Digital Workspaces

▶ Collaborative Environments for Augmented and Virtual Reality Applications

Shared Environments

▶ Collaborative Environments for Augmented and Virtual Reality Applications

Shooter

▶ Fortnite: A Brief History

Sight Loss

▶ Unified Modeling Language (UML) for Sight Loss

Silver Halide

▶ Holography as an Architectural Decoration

Sim

▶ Immersive Technologies for Medical Education

SIMBICON - Simple Biped Control

▶ Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality

Simulated Environment

▶ Origin of Virtual Reality

Simulation

▶ Distributed Simulation and Games

Simulation and Comparison of AODV and DSDV Protocols in MANETs

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Synonyms

AODV; DSDV; NS-2 simulation; Protocol

Definition

The MANET network is a network of wireless hosts that can be mobile. In MANET networks, the mobility of the nodes may change the path between the two nodes and this makes them different from other wireless networks.

Introduction

Wireless networks consisting of several nodes have no centralized infrastructure. Routing causes data to be transmitted from source to destination. An effective way to estimate the performance of these networks is to simulate the performance of different protocols depending on the environment and the type of simulator used. In this article, the performance of both AODV and DSDV protocols in terms of metrics was evaluated. Cellular systems will no longer sustain the recent, rapidly growing demand for applications like VoIP, Internet surfing, online games, etc., due to their limited capacity and data rate.

Ashheb study reveals that two protocols AODV and DSDV have been simulated using NS-2 simulator and compared in terms of packet delivery fraction, end to end delay, and throughput in different environment, varying period of pause time and the number of expired nodes. Simulation results show that AODV routing protocol has better performance in terms of packet delivery fraction and throughput but AODV suffers from delay (El Ashheb 2012). Neetu et al. discussed the performance of DSDV and AODV routing protocols measured using the different performance metrics such as Packet Delivery Fraction, Average End to End delay, and Routing Overhead under two different scenarios, with changing pause time and changing number of nodes. It was observed that the performance of AODV routing protocols is much superior as compare to the DSDV routing protocol (Neetu 2012).

MANET Networks

The MANET network is a network of wireless hosts that can be mobile. No prefabricated infrastructure is used in these networks (necessarily). That means, there is no infrastructure such as a central station, router, switch, or anything else that is used in other networks to help with network structure. Rather, there are only a few wireless nodes that connect to non-neighboring nodes by connecting to neighboring nodes (Suman et al. 2009).

In MANET networks, the mobility of the nodes may change the path between the two nodes and this makes them different from other wireless networks. Despite all these problems, MANET networks are used in many cases. The reason is the speed and ease of implementation of this network, as well as its reliance on pre-built structures.

Uses of MANET networks include personal applications such as connecting laptops to one another, general applications such as communication between vehicles and taxis, military applications such as military and fleet communication, and emergency applications such as rescue operations. Now days we have latest several multimedia applications such as digital television, video conferencing, web games, and real-time interactive audio and video streaming which needs high throughput and less amount of end to end delay which are main essential quality of service metrics (Sharma and Trivedi 2016).

AODV and DSDV Protocol Performance

Using Flooding Algorithm for Data Transfer

The simplest solution to the problem of routing in wireless networks is to transfer information through flooding. This is the way the sender sends information to all of its neighbor nodes. Any node that receives a packet sends this information to its neighbors. To prevent a node from sending a packet more than once, a sequence number is used for each packet. Each receiver thus controls the sequence number of the packet and sends it to its neighbors if it is not a duplicate. This method will definitely reach the destination, but once the destination has been reached, the flooding operation will continue to reach all the nodes in the packet (Kumar and Miglani 2009).

As is clear, the main advantage of this method is first of all its ease of implementation and secondly the assurance of destination-based access. However, one major drawback to the scheme is that data packets are often high in volume and, as explained in this way, data may travel the distance without needing to. For example, suppose a node decides to use data to send to its neighbor node. Now if you want to use the flooding method, this packet will be distributed all over the network. If you know the neighborhoods of the nodes, you can greatly reduce this information transfer.

This drastic increase in network load does not allow the flooding method to transfer information. But this method is widely used in moving control signals due to the small volume of these signals. Control packets are packets that are used to obtain the route and are the routes used to send the data (Vijayalaskhmi et al. 2011).

DSDV Protocol

The Destination Sequenced Distance Vector protocol (DSDV) is based on the classic Bellman-Ford algorithm. In this case, each node provides a list of all destinations and the number of jumps to each destination. Each list entry is numbered with a number. Incremental packets are used to reduce the amount of traffic caused by network updates. The only advantage of this protocol is to avoid the creation of routing loops in networks containing mobile routers. This way, route information is always provided, regardless of whether the node currently needs to use the route. The disadvantages of the DSDV protocol require parameters such as the timeframe for updating information and the number of updates required (He 2002).

AODV Protocol

In the Advanced On-demand Distance Vector algorithm, unlike the previous algorithm, it does not place the path in the packet header. So, each node controls the table it already has when receiving RREQ. If the path of final node exists on your table, then the RREP issued. Otherwise, it broadcasts the RREQ message. Certainly RREPs can be sent back to the RREQ transmitter node. In order for a middle node to know if the path he knows is newer to the request, a sequence number is used in the RREQ messages. Thus, only if the RREQ sequence number is less than the path sequence number, the RREP message is issued by the middle node (Bobade and Mhala 2012).

Other Algorithms

There are many other algorithms for routing in wireless networks. These algorithms include location-based algorithms such as LAR and DREAM. These algorithms predict the current position of a node using information such as the previous position and speed of a node and send the message only to the same region. Due to the multitude of routing algorithms in these networks, just a few specific algorithms in this article were mentioned.

NS-2 Simulator

NS-2 is a computer network simulator based on discrete and object-oriented simulator. Written by C++ and Otcl programming languages, it is one of the most useful tools for simulating local and wide area computer networks.

Simulation and Comparison of AODV and DSDV Protocols

The simulation is performed on 50 randomly moving nodes in an insecure wireless network that has 25 source nodes with TCP application and CBR traffic type, maximum packet size is 1000 bytes and 25 destination nodes is selected using LossMonitor and TCP pattern.

In this discussion, each node with a node number sends information to a node with an odd number of units at a time, the nodes moving randomly in a wireless environment. The scenario presented by the two types of AODV and DSDV protocols is applied to the nodes in the environment.

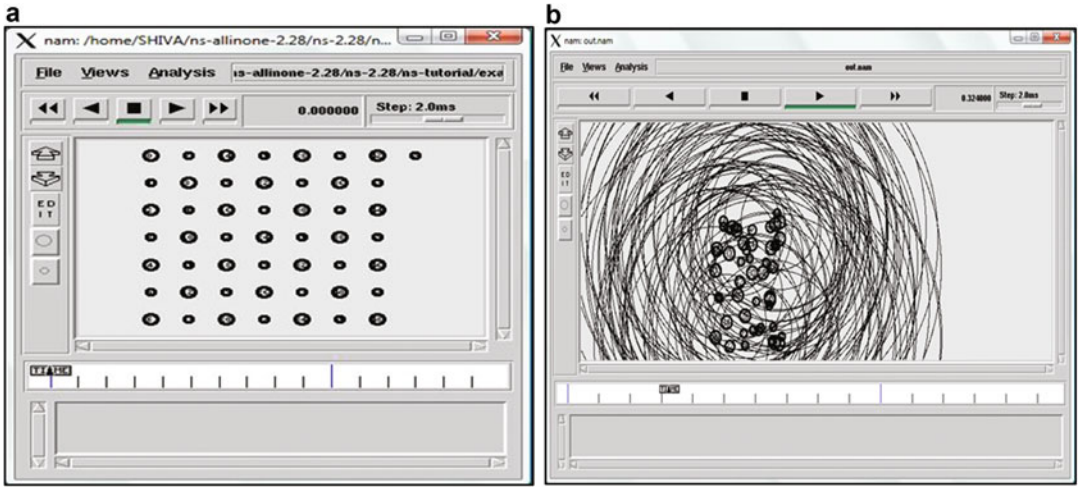
Nam is a Tcl/TK-based animation tool for viewing network simulation traces and real world packet traces. It supports topology layout,

packet level animation, and various data inspection tools. Nam with 50 nodes is shown in Fig. 1a. Figure 1b shows NAM with transmission information.

Scenario1: AODV Protocol with 50 Nodes

The parameter specifications of the scenario1 with the AODV protocol are presented in Table 1. Parametric specifications are number of nodes, simulation time, type of traffic, etc.

At the beginning of the scenario1, both the bandwidth metrics and the number of packets loss are zero. Packets loss occurs when one or more packets traveling across a network fail to reach their destination. Packet loss can be caused by a number of factors, including signal degradation over the network, oversaturated and highly congested network links, corrupted and faulty packets rejected, and faulty networking hardware (Rathee and Verma 2009). After the CBR is applied to the nodes, the movement of nodes around the number of packets loss per unit of time is increasing and is graphically displayed. The performance of AODV protocol is shown in Fig. 2. The green chart shows the number of packets received and the red chart shows the packets loss. As you can see, as the number of packets received increases, as well as the number of packets loss increases.



Simulation and Comparison of AODV and DSDV Protocols in MANETs, Fig. 1 (**a**) NAM with 50 nodes. (**b**) NAM with transmission information

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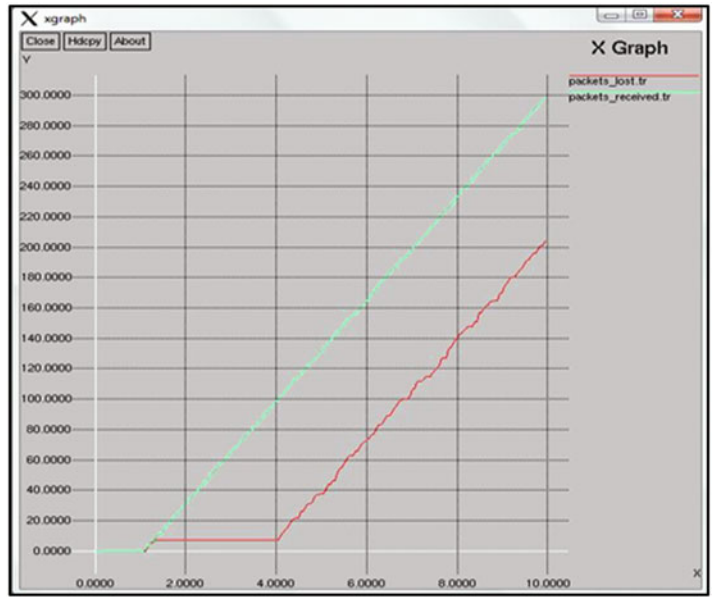
Simulation and Comparison of AODV and DSDV Protocols in MANETs, Table 1 Parametric specifications of scenario1

Parameter	Value
The number of nodes	50
Simulation time	10 s
Type of protocol	AODV
Environment size	800 × 400
Type of traffic	CBR
Packet size	1000 byte
Simulator version	Ns-2.28
Antenna type	Omni antenna



Simulation and Comparison of AODV and DSDV Protocols in MANETs, Fig. 2 The performance of AODV protocol

Simulation and Comparison of AODV and DSDV Protocols in MANETs, Table 2 Parametric specifications of scenario2

Parameter	Value
The number of nodes	50
Simulation time	10 s
Type of protocol	DSDV
Environment size	800 × 400
Type of traffic	CBR
Packet size	1000 byte
Simulator version	Ns-2.28
Antenna type	Omni antenna

Scenario2: DSDV Protocol with 50 Nodes

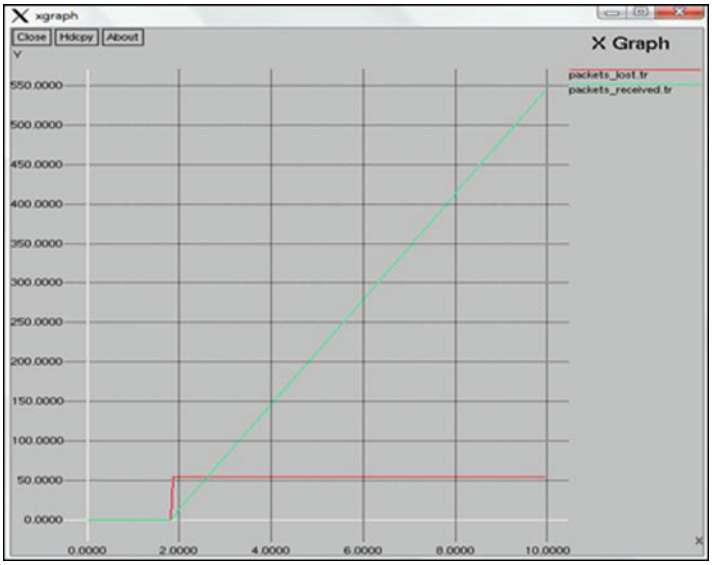
The Parameter specifications of the scenario2 with DSDV protocol are presented in Table 2. At the beginning of the scenario2, both the bandwidth metrics and the number of packets loss are zero. So, the only difference between scenario1 and scenario2 is in the type of protocol. The performance of DSDV protocol is shown in Fig. 3.

Performance Comparison

The number of packets loss in AODV increases with increasing simulation time, but this criterion in DSDV decreases with increasing simulation time and follows a constant rate. Therefore, in wireless networks, if there is less time to transmit data, it is better to use the AODV protocol because it has fewer packets loss.

Conclusion

In this article, the performance of both AODV and DSDV protocols in terms of metrics was evaluated. NS-2 simulator for comparison the performance of AODV and DSDV protocols is used. Both AODV and DSDV protocols can be used in environments where there is more communication



Simulation and Comparison of AODV and DSDV Protocols in MANETs, Fig. 3 The performance of DSDV protocol

time, because often the rates for packets loss are the same. But AODV has better packet received rate than DSDV.

Cross-References

► Client/Server Gaming Architectures

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Simulation for Therapy

► Virtual Reality Therapy

Simulation Game

► NBA 2K, a Brief History

Simulation of Crowd Emotion

► Simulation of Emotional Crowd and Applications

Simulation of Emotional Crowd and Applications

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Synonyms

Emotional contagion; Simulation of crowd emotion

Definitions

Emotional contagion	The emotion of a whole group converges as individuals affect nearby people while the whole group affects the individuals.
Simulation of crowd emotion	Emotion of crowds is simulated by computer algorithms based on personalities of agents, events, and emotional contagion.

Introduction

A crowd is a large group of diverse people gathering closely in the same physical space. Crowds are commonly seen in transportation centers, theaters, shopping malls, and parks. Behaviors of a group are influenced by group emotion which is one of essential factors for modeling realistic groups. *Emotions are an inherent part of group life. Individuals bring their unique emotional tendencies to the group, and the composition and interaction of those emotions produce emotional heat which goes on within, among, and beyond the tendencies of individual members. These group emotions have been viewed as moving from the group level downward (a top-down approach), as well as moving upward from the compositional effects of individual group member emotions (a bottom-up approach)* (Barsade and Gibson 1998). Based on these observations, we can investigate the propagation mechanism of group emotion and then develop techniques to simulate emotion of individuals and crowd. Subsequently, diverse behaviors of crowds induced by different emotion types can be simulated. Crowd simulation techniques have a wide range of applications, such as the layout design of parks, crowd evacuation, crowds in shopping malls, and modeling interaction between pedestrians and vehicles.

To build up a simulation model, we need a model of individuals and a group model. An essential attribute of such models is personality which refers to characteristics of a person that account for consistent patterns of feeling, thinking, and behaving (Cervone and Pervin 2015). In general, a person's personality influences how much the way that he feels; and people influence each other's emotion. A person performs an action based on his current emotion and the received influence. We model a crowd as a set of agents. An agent has many attributes, such as position, velocity, walking speed, desired walking speed, personality, emotion, action, desire, belief, and intention. The agents of a crowd can interact with each other in an environment. An agent's emotions and related behaviors can trigger similar emotions and behaviors of neighboring agents and vice versa. This phenomenon is called emotional contagion (Baig et al. 2014). A simulation technique requires the following items to simulate the emotion of an agent i:

1. An emotion model represents the emotion e of an agent.
2. A personality model represents personality of an agent.
3. A stimulus model represents the stimulus that affects an agent's emotion. The stimulus can be from surrounding agents and the environment.
4. An emotional contagion model represents how the surrounding agents affect each other.

In a simple form, the emotion of agent i can be updated as follows:

$$e_i(t + \Delta t) = e_i(t) + \Delta e_i \Delta t, \qquad (1)$$

where $e_i(t)$ is the current emotion, Δe_i is the emotion change, Δt is the simulation time step, and

$e_i(t + \Delta t)$ is the new emotion. We would like to find a way to determine Δe_i so that the new emotion of agent i can be evaluated. In general, an agent has its own emotion. The neighboring agents and the environment generate a stimulus on the agent. The degree of influence of the stimuli on the agent depends on the agent's personality and perception. Subsequently, the agent changes its emotion over time. At the meantime, the agent also affects the emotions of its neighboring agents. Some agents may be easily influenced by others while some may be able to manage to converge their emotions.

The organization of the rest of entry is as follows. The next section presents personality dimensions and some personality models. Then we present approaches for emotion modeling. After that emotion contagion is presented. Finally, we present some applications and conclude this entry.

Personality Dimensions

Personality psychology studies personality and its variation among individuals. Personality can be encapsulated by certain factors in a continuum. Studies show that a certain set of words can be used to describe aspects of personality to the same person. Factor analysis, which is a fundamental tool in statistics, uses a small set of unobserved variables called factors to describe variability among observed variables. The observed variables are modeled as linear combinations of the factors. Every individual has his own personality that can be represented by many words. Among such words, some of them are dominant and thus we can use fewer words to represent the individual personality.

One of the fundamental problems of personality psychology is identifying the major dimensions of personality variation. We need a representative sampling of the universe of those variables to construct the structure of personality characteristics. The psycholexical approach can be adopted to produce such representative samples. The psycholexical approach is emerged from personal psychology (De Raad 2000), which has two postulates about personality characteristics (Widiger 2017):

1. The important personality characteristics of a group will become a part of the group language.
2. More important personality characteristics are more likely to be represented as a single word (or term) in the language.

By applying the principles of the psycholexical approach, we can group words with similar meanings and then obtain models with a few factors for describing people. Some five-factor models are selected as representatives among all the models. Five-factor models represent the personality of people based on five dimensions. In this entry, we present several five-factor models and the Hexaco model with six dimensions (Lee and Ashton 2013). In personality psychology literature, different personality models (with more dimensions) have been proposed for incorporating more common dimensions for accounting individual difference. Due to richness of human individuality and evolving life habits, the personality models can be changed over time.

The OCEAN Model (Big Five Personality Traits)

The OCEAN model, which is a five-factor model (Fig. 1), has five personality traits. We denote the

Simulation of Emotional Crowd and Applications, Fig. 1 The OCEAN model

five factors of the OCEAN model as $\{\psi^O, \psi^{\mathbf{C}}, \psi^E, \psi^A, \psi^N\}$. The value of each factor is inside [0, 1], in general. The five factors and their traits are listed as follows (Barrick and Mount 1991):

1. Openness to experience (ψ^O): Inventive/Curious vs. Consistent/Cautious
   Traits: Being imaginative, cultured, curious, original, broad-minded, intelligent, and artistically sensitive
2. Conscientiousness (ψ^C): Efficient/Organized vs. Easy-going/Careless
   Traits: Reflecting dependability; that is, being careful, thorough, responsible, organized, and planful
3. Extraversion (ψ^E): Outgoing/Energetic vs. Solitary/Reserved
   Traits: Being sociable, gregarious, assertive, talkative, and active
4. Agreeableness (ψ^A): Friendly/Compassionate vs. Challenging/Detached
   Traits: Being courteous, flexible, trusting, good-natured, cooperative, forgiving, softhearted, and tolerant.
5. Neuroticism (ψ^N): Sensitive/Nervous vs. Secure/Confident
   Traits: Being anxious, depressed, angry, embarrassed, emotional, worried, and insecure.

Besides the OCEAN model, there are different kinds of five-factor models across countries (De Raad 2000). The following lists some examples:

1. The Norman five-factor structure: Extraversion, agreeableness, conscientiousness, emotional stability, culture
2. The American-English five-factor structure: Extravesion/surgency, agreeablness, conscientiousness, emotional stability, and intellect
3. The Dutch five-factor structure: Extravesion, agreeablness, conscientiousness, emotional stability, and intellect
4. The German five-factor structure: Surgency, agreeableness, conscientiousness, emotional stability, and intellect

The HEXACO Model

Lee and Ashton (2013) proposed the HEXACO model of personality as an alternative to the five-factor models. The HEXACO model is constructed based on the cross-cultural research (Ashton et al. 2004) in seven countries, including Dutch, French, German, Hungarian, Italian, Korean, and Polish. The HEXACO model (Fig. 2) has an additional trait Honesty-humility, compared to the Big Five model. Each factor of the HEXACO model has four facets (Ashton and Lee 2009). The six factors and their facets are listed as follows:

1. Honesty-humility: Fairness, greed-avoidance, modesty, sincerity
2. Emotionality: Anxiety, dependence, fearfulness, sentimentality
3. Extraversion: Liveliness, social boldness, social self-esteem, sociability
4. Agreeableness versus anger: Forgiveness, gentleness, flexibility, patience
5. Conscientiousness: Diligence, organization, perfectionism, prudence
6. Openness to experience: Aesthetic appreciation, creativity, inquisitiveness, unconventionality

Simulation of Emotional Crowd and Applications, Fig. 2 The HEXACO model

Although the five-factor and Hexaco models are simple, they have undesirable features. For example, Ashton (Ashton and Lee 2009) commented on three undesirable features in the HEXACO60 model. First, the scales' inter-item correlations or internal consistency reliabilities may not be high. Second, each of the scales may not be unidimensional. Third, the facets in each trait are not expected to define their intended factors univocally. The facets may have nontrivial secondary loadings.

Emotion Models

Ortony et al. proposed an OCC (Ortony, Clore and Collins) model (Ortony et al. 1990) which states that the emotions are valanced reactions to events, agents, and objects. These events, agents, and objects can be either pleasing or displeasing to the subject under consideration. The OCC model classifies 22 different emotions by evaluating (1) consequences of events (happy or unhappy), (2) aspects of objects (like or dislike), and (3) actions of agents (approve or disapprove).

A bipolar circumplex model represents emotion in a two-dimensional (2D) spatial domain, such as the valence-arousal model proposed by Russell (1980). The Russell's valence-arousal model has two orthogonal axes. The vertical and horizontal axes represent arousal and the degree of valance, respectively. Valence reflects the degree of the response from positive to negative (or *pleasant* to *unpleasant).* Arousal indicates the level of activities associated with the emotional response between two extremes which are very *excited* and very *calm* (or *sleepys).* The Russell's model can present a variety of emotions based on the combinations of positive/negative and passive/active pairs (Li et al. 2013). For example, we have the following four types of emotions:

1. Positive-active emotions: Examples are *excited, happy, hope,* and *interested.*
2. Positive passive emotions: Examples are *relaxed, calm, content,* and *satisfied.*
3. Negative-active emotions: Examples are *angry, frustrated,* and *irritated.*
4. Negative-passive emotions: Examples are *bored, fatigue, sadness,* and *tired.*

The PAD model (Mehrabian 1996), which has three dimensions, is a general framework for describing and measuring individual differences in temperament. In general, an individual reacts to the world based on his/her personality traits that constitute one's temperament. The meanings of the three dimensions are as follows:

1. Valence (quality): Unpleasant to pleasant. Valence represents positive or negative affective states.
2. Arousal (quantity): Calm to excited. Arousal indicates the mental and/or physical activity level.
3. Dominance (control): Weak to strong. Dominance indicates the ability for controlling over others or situations.

Intelligent Agent Modeling

Rao and Georgeff (1991) proposed a BDI-architecture which has three attributes: belief, desire, and intention. The emotion of agents affects the desires, decision and action of the agents.

1. Beliefs represent the cognitive information that an agent has about a virtual environment. The cognitive information includes the data describing environmental characteristics and other nearby agents.
2. Desire indicates the initial motivation of an agent. In other words, it is the state that the agent wants to accomplish. The agent has certain desires under specific situations.
3. Intention indicates the current action that an agent intends to take so that the agent can accomplish its own desire.

The BDI architecture can solve the problem of agents' goal programming and decision making. We can integrate the three models, PAD, personality (e.g., OCEAN), and BDI, to simulate diverse behaviors of agents in public emergency (Mao

et al. 2019). The beliefs, desires, and intention of an agent can be affected by the emotion of the agent.

Crowd Types, Emotion, and Action

We can classify crowd situations based on the presence of an event and the level of interactions in crowds. In general, event and nonevent crowds are the two most common situations (Li et al. 2013). People of an event crowd want to interact with each other in performances or activities, such as concerts, conferences, church gatherings, and parties. However, people of a nonevent crowd want to achieve an external goal or to obtain benefits in joining the crowd. Nonevent crowds do not take part in any activities or performances.

Studies show that crowd with certain kinds of emotions tend to perform certain actions (Li et al. 2014). The study reveals that there is an association between emotional feelings and actions. The study employed a set of 13 crowd emotional feelings, including six positive and seven negative ones, and investigated the corresponding action tendencies (Frijda et al. 1989). The actions include *be with, protection, attending, avoidance,* and *rest.* The study reports that, in general, people do not have any action tendencies when they feel positive in event crowds. Furthermore, negative action tendencies are not linked with negative emotional feelings.

Modeling Emotional Crowds

We can simulate socially emotional crowds based on an emotion network structure (Lyu and Zhang 2018). In the emotion network structure, a network node and a relationship arc represent an individual emotion space and a psychological linkage, respectively. Furthermore, an emotion tree represents an emotionally homogeneous crowd. Initially, each crowd is modeled as an emotion tree which has an emotion component that is evaluated to be a value (scalar or a vector). Therefore, we can determine the psychological distance between the emotion trees of every two individual crowds. The agents in an emotion tree have similar emotion and they often tend to interact with one another. While the agents in a crowd or crowds interact with each other, the emotions of the agents can change gradually due to their diverse personality characteristics. Hence, the relational distributions of the agents change over time. Subsequently, the agents move between different subgroups while they interact with each other in a long time period. Of course, if two crowds exhibit similar emotion, they can be merged.

A traditional system for simulating the emotion of an agent has two layers, a physical layer ($\mathbf{L}_\mathrm{P}$) and a decision layer ($\mathbf{L}_\mathrm{D}$). The functions of the two layers are as follows:

1. The physical layer handles navigation, collision prevention, interaction with others, and motion execution.
2. The decision layer collects and processes data around the agent. It also performs data analysis and decision making.

The physical layer is defined as follows:

$$\mathbf{L}_P = \left\{ \Phi_{phy}, \Psi_{env} \right\}, \tag{2}$$

where Φ_{phy} is a dynamic structure that is relevant to crowds and contains a set of physical states about the environment, including agents and movable regions; and Ψ_{env} is a structure that represents the states of geometric entities and paths in an environment.

The decision layer $\mathbf{L}_\mathrm{D}$ depends on the environment information, such as agents and other objects. The crowds may have some initial targets Ω_{tar} that depend on the intentional states of crowds, Φ_{int}. Furthermore, the crowds can be affected by environmental events Ψ_{eve} and the physical environment information collected by $\mathbf{L}_\mathrm{P}$. These two factors Ψ_{eve} and $\mathbf{L}_\mathrm{P}$ are considered when crowds make the movement decisions in a dynamic manner. Therefore, we define $\mathbf{L}_\mathrm{D}$ as follows:

$$\mathbf{L}_D = \{ \Omega_{tar}, \Phi_{int}, |\mathbf{L}_P \}. \tag{3}$$

Finally, we denote Φ_{emo} as the set of crowd emotional states and define the emotion layer ($\mathbf{L}_\mathrm{E}$) as follows:

$$\mathbf{L}_E = \{\Phi_{emo} | \mathbf{L}_P, \mathbf{L}_D\}. \quad (4)$$

$\mathbf{L}_E$ depends on both layers $\mathbf{L}_P$ and $\mathbf{L}_D$. In general, an agent collects data from the environment and analyzes the data to make decision while the agent moves to its target. However, the environment may change in a dynamic manner and thus the emotion of the agent can be affected by other agents and events in the environment. Subsequently, the agents change its decisions and perform appropriate actions from time to time. To summarize, the simulation process has the following steps:

1. We invoke the emotion layer $\mathbf{L}_E$ to update the emotion states of crowd. The emotion layer handles the emotion contagion process in a dynamic manner.
2. $\mathbf{L}_D$ is invoked for agents to collect external information, including the environment information, nearby agents, and surrounding objects. Then it analyzes the internal intentions of the agents. Finally, it decides the targets and actions of crowd.
3. The decision layer $\mathbf{L}_D$ send decisions to the physical layer $\mathbf{L}_P$. The physical layer determines the feasible paths based on the geometric information. While agents are moving to target positions, $\mathbf{L}_D$ performs collision avoidance for them. Because the environment is changed in a dynamic manner, the paths for the agents are updated accordingly.

In the decision layer $\mathbf{L}_D$, the function *update* computes the new velocities of agents $\mathbf{v}_d$. We consider several factors in updating the decisions for a crowd, including (1) the emotion-controlled velocity of agents $\mathbf{v}_e$, (2) an algorithm of a finite state machine Γ_{fsm}, and (3) an algorithm for navigation Γ_{nav}. The finite state machine Γ_{fsm} traces the states of the agents and can be used for determining the decisions of the agents. The navigation algorithm Γ_{nav} computes the optimal paths for the agents based on the agent decisions. Formally, the prototype of the function is defined as follows:

$$\mathbf{v}_d \leftarrow \mathbf{L}_D.update\left(\mathbf{v}_e, \Omega_{int}, \Phi_{phy}, \Psi_{env}, \Psi_{eve}, \Gamma_{fsm}, \Gamma_{nav}\right). \quad (5)$$

Note that the decision layer $\mathbf{L}_D$ does not consider the physical environment thoroughly when a decision is made. Thus, an agent may move in a direction that leads to collision. Thus, we need to rely on the physical layer to adjust $\boldsymbol{v}_d$ properly. We employ the physical layer to compute the final velocities of the agents. In this sense, an algorithm Γ_{col} for collision avoidance is required while the agents are moving in the environment. Formally, the prototype of the *update* function in $\mathbf{L}_P$ is defined as follows:

$$\mathbf{v}_p \leftarrow \mathbf{L}_P.update\left(\mathbf{v}_d, \Phi_{phy}, \Psi_{env}, \Gamma_{col}\right). \quad (6)$$

While the agents interact with each other, their emotions change over time. The agents may come together if their emotions are similar to each other. Therefore, we can use emotion trees to manage the agents with similar or dissimilar emotions. Furthermore, we employ the emotion trees to perform interaction between groups.

Thus, an emotion tree encapsulates the emotion propagation among individuals in groups. We consider the following factors to build an emotion tree for a group:

1. An emotion tree should encapsulate the internal emotion values of a group, denoted as δ_{int}. Thus, we can use such internal values to identify the group. The internal values include the threshold of emotion energy, the interaction period related to emotions of the group, and the overall emotions of the tree.
2. The group has a set of members, denoted as ϕ.
3. The group has a representative that is the root of group *root*. The root has several functions that be easily extracted in simulation. For example, the root can be the center, goal, or target of the group.
4. Emotions of the group can give impact to the other groups in a nearby region. We denote δ_{emo} as the group emotion values that can influence other groups. The set of values include emotion concentration levels, density, and the covered region.
5. The members of the group move in a spatial domain. Thus, they are bounded inside a region which has the minimum area. The region has a boundary Ω that encloses all the

members. Because the members are moving, the shape of the region changes. Therefore, the boundary Ω deforms over time.

6. We need a database M_o of action clips that are labeled for various types of emotions and behaviors. Thus, we can use an action clip to animate an agent accordingly.

Formally, we define an emotion tree as follows:

$$\mathbf{T}_E = \{\delta_{int}, \delta_{emo}, root, \phi, \Omega, M_o\}. \quad (7)$$

An emotion tree has a set of relationship arcs connecting agents. Relationship arcs are psychological links which are used for modeling emotion propagations of agents. The individual emotion model represents an agent's emotion and consists of three components: an emotion space (E), personality (p), and an emotional command space (C) which is constructed based on emotion rules. The emotion space is represented as the wheel of motion which has four pairs of opposing basic dimensions (Plutchik 2001). The four basic dimensions are: *surprise-interest, sadness-happiness, fear-anger,* and *disgust-trust.* In general, an agent performs a certain action which is selected from M_o based on its current emotion.

Contagion of Panic Emotion in Multihazard Environments

We employ crowd emotion to simulate the micro-level behavior of crowd in multihazard environments (Xu et al. 2019). We report the method proposed by Xu et al. as follows.

We classify hazards into six types based on three attributes as follows.

1. Durations: How long does a hazard last?
   a. A transient hazard: Individuals are threatened for a short period when the hazard occurs. After the hazard disappears, the individuals are no longer affected by it.
   b. A persistent hazard: Individuals are threatened for a long period when the hazard occurs. Furthermore, the hazard continues to affect the individuals in the area around it over its life time.

   A crowd and individuals can change adversely their psychological states when they encounter these two types of hazards. They must respond immediately to escape from such dangerous areas.
2. Time of occurrence (generation time): When do the hazards occur?
   a. Concurrent hazards: Individuals are affected concurrently by two or more hazards during the same period. The influences of the hazards can be treated as a single hazard and their impacts are accumulated.
   b. Nonconcurrent hazards: Individuals are affected by the hazards individually. Furthermore, the effects of a new hazard influence the agents in an accumulative manner. In other words, the agents can receive multiple impacts of different types from hazards of various types.
3. Dynamics or mobility: Does a hazard change its position or the influence area?

   A hazard has two main attributes, position and influence region.
   a. Static hazards: Their positions and influence regions do not change.
   b. Dynamic hazards: A dynamic hazard has at least one attribute which is changed over time. Therefore, the position and influence area of such a hazard must be determined in a dynamic manner over a time horizon.

   The hazards make their influence regions become dangerous. Furthermore, they have great impacts on the emotions and decision making of a crowd. Consequently, the movement of the entire crowd is affected. The agents tend to move to safe regions when hazards occur. When the physical and decision layers update paths and crowd emotions, the hazards must be considered.

Several close hazards occur in a finite time horizon and form a dangerous field. They give direct impacts on the nearby agents when they occur. We can use a function which converses the intensity of danger induced by these hazards to panic emotion. Furthermore, in the influence

region of the hazards, the agents affect each other and panic emotion propagates among themselves. The process of the emotion propagation among the agents can be simulated based on an emotional contagion model (ECM). Mainly, the emotional contagion model computes how the emotion of an individual agent affects other agents (bottom-up) and how the emotion of a group affects individual agents (top-down). It requires several essential factors to compute the panic emotion of an agent. For example, the factors include the following: (1) the distance between a hazard and the agent; (2) the personality of the agent; (3) the nearby agents of the agent; (4) the distance between the agent and the nearby agents.

A hazard s covers a finite region A_s called dangerous range with a boundary γ_s. It has an influence radius, r_s. In the case that the hazard s is dynamic, its area grows and its position can move over time. Furthermore, the hazard s generates a field of danger over a time horizon U (i.e., a time duration). We assume that the strength of danger, $\Gamma_s(\mathbf{q}, t)$, at the position $\mathbf{q}$ can be evaluated at time t. $\Gamma_s(\mathbf{q}, t)$ is a constant inside the hazard area but becomes smaller for a larger distance. Formally, we have

$$\Gamma_s(\mathbf{q},t) = \begin{cases} 1 & \text{if } \mathbf{q}\in A_s, \text{ and } t\in U \\ \frac{1}{\sqrt{2\pi}\cdot r_s} e^{-\frac{(\mathbf{q}-\mathbf{q}^\gamma)^2}{2r_s^2}} & \text{if } \mathbf{q}\notin A_s, \left\|\mathbf{q}-\mathbf{q}^\gamma\right\| < r_s, \text{ and } t\in U \\ 0 & \text{otherwise.} \end{cases}$$

Here, $\mathbf{q}^\gamma$ ($\in \gamma_s$) is on γ_s and closest to $\mathbf{q}$. The strength of danger affects how quickly the panic emotion of an affected agent grows.

Denote H as the set of all the hazards, that is, $H = \{h_1, h_2, \cdots, h_n\}$. We accumulate the strengths of danger of the hazards which affect an agent i to compute the panic value of the agent. The panic value $E_i^h(\mathbf{q}, t)$ of agent i is computed as follows:

$$E_i^h(\mathbf{q},t) = \sum_{s\in H} \Gamma_s(\mathbf{q},t). \tag{8}$$

Besides hazards, an agent's personality and nearby visible agents affect the decision making of the agent. The personality of the agent has impacts on how fast the agent influences other agents and vice versa. On the one hand, the agent has an ability to express the degree of peril to one another. On the other hand, other nearby agents also influence the agent by a certain amount. In these two cases, we use two thresholds, expressiveness (e^{T_i}) and susceptibility (s^{T_i}), for checking whether the agent delivers successfully the hazard warning to others and being affected by others, respectively. Thus, the agent warns successfully to the other agents if its emotional value higher than its expressiveness threshold. Similarly, if the emotion value of the agent i is larger than s^{T_i}, the agent is affected by the other agents. The two thresholds are computed as follows:

$$e^{T_i} \sim N\left(0.5 - 0.5\psi_i^E, \left((0.5 - 0.5\psi_i^E)/10\right)^2\right), \tag{9}$$

and

$$s^{T_i} \sim N\left(0.5 - 0.5\varepsilon_i, \left((0.5 - 0.5\varepsilon_i)/10\right)^2\right), \tag{10}$$

where N(·,·) represents a normal distribution with the first parameter as the mean and the second parameter as the standard deviation; $\varepsilon_i (\in [-1, 1])$ is the empathy value for agent i. Denote $M_P = \{O,C,E,A,N\}$. We can compute the empathy value based on the OCEAN model. Formally, we have.

$$\varepsilon_i = \sum_{j\in M_P} c^j \psi^j, \tag{11}$$

where $c^O = 0.354$, $c^C = 0.177$, $c^E = 0.135$, $c^A = 0.312$, and $c^N = 0.021$ (Jolliffe and Farrington 2006).

Denote V (i) as the set of agents in the perceived range of agent i. We compute the effect caused by all the agents j ∈ V(i) as follows:

$$E_t^c(P,t) = \sum_{t'=t-k+1}^{t} \sum_{j=1}^{n} d_i(t') E_j^{c'}(P_j, t'), \tag{12}$$

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where $d_i(t') \sim N(0.1,0.0001)$ is the dose value which agent i received from agent j at time t; $E_j^c(P_j,t)$ is the panic emotion of agent j ∈ V(i) at time t. The value of k is the duration for emotional accumulation of agent i at time t.

The panic emotion of individuals decays gradually to the normal state. This process can be formulated by using an emotional attenuation function. Denote η as the emotional decay rate and $\mathbf{q}^{\text{pre}}$ the position at the previous time step. Thus, the new panic of agent i is computed as:

$$E_i^d(\mathbf{q},t) = E_i(\mathbf{q}^{pre},t-1)\cdot\eta, \eta\in(0,1]. \quad (13)$$

The total panic emotion of agent i at position $\mathbf{q}$ is computed by.

$$\Delta E_i(\mathbf{q},t) = E_i^h(\mathbf{q},t) + E_i^c(\mathbf{q},t) - E_i^d(\mathbf{q},t) \quad (14)$$

$$E_i(\mathbf{q},t) = E_i(\mathbf{q}^{pre},t-1) + \Delta E_i(\mathbf{q},t) \quad (15)$$

We can determine the stressful behaviors of the agents after all the agents are processed. Denote $\mathbf{q}$ and $\mathbf{v}_i^s$ as the position and velocity of an agent, respectively. When the agent is affected by a hazard s at position $\mathbf{q}_s$, it attempts to follow a safety direction $\mathbf{u}$ (i.e., along $\mathbf{q}^\gamma - \mathbf{q}_s$) to escape, where $\mathbf{q}^\gamma$ is a point on γ_s and closest to the agent. Of course, if the agent is not inside the impacted area of any hazard, it moves along its desired direction $\mathbf{v}_i$. Thus, we can determine the expected movement direction of the agent under multihazards as follows:

$$\mathbf{v}_i^s(\mathbf{q},t) = \begin{cases} \Sigma_{s=0}^{n-1}\Gamma_s(\mathbf{q},t)\cdot\mathbf{u} & \text{if } \left\|\mathbf{q}-\mathbf{q}_s\right\| < r_s \quad \text{and } t\in U \\ \mathbf{v}_i & \text{otherwise.} \end{cases}$$

Assume that the probabilities of agent i following its desired direction and others' directions are p, and $1-p$, respectively. Thus, we can determine the final movement direction of the agent as follows:

$$\mathbf{v}_i^c(\mathbf{q},t) = E_i(p,t)\mathbf{v}_i^s(\mathbf{q},t) + (1-E_i(\mathbf{q},t))\sum_{j\in R(i)}\mathbf{v}_j^c\left(\mathbf{q}_j,t\right), \quad (16)$$

where $\mathbf{v}_i^c(\mathbf{q},t)$ represents the moving direction of agent i at position $\mathbf{q}$ at time t; *R(i)* is the set of neighboring visible agents of agent i. On the right side of the equation, the velocities of the agents under the hazard impact cannot be determined. We can initially set those velocities of the agents by using Eq. 15. And then we perform Eq. 16 for a few times to determine the final velocities of the agents.

Each agent has a desired movement direction. However, if the agent is affected by external factors such as hazards and nearby agents, the agent has to determine its final direction. Furthermore, the agent should consider the appropriate global paths for moving to a target while collision avoidance is achieved. To locally determine the final movement direction of agents, we can adopt the navigation algorithms, such as reciprocal velocity obstacle (RVO) (Van den Berg et al. 2008), radial view based method (Wong 2016), vision-based method (Dutra et al. 2017), and predefined evacuation routes (Wong et al. 2017).

Applications

Emotional group simulation can be applied to a wide range of domains to enrich the realism of virtual agents, such as simulation of rare pedestrians behaviors, self-driving learning systems, pedestrian trajectory prediction, terrorist attacks, and crowd evacuation. The decision making of agents is affected by its personality, the surrounding agents, dynamic objects, and environments. We give some application examples as follows.

Mao et al. (2019) present an emotion-based diversity behavior model, by adopting the OCEAN personality model and the OCC emotion model. Their method is integrated with a CA-SIRS emotion contagion model. The model considers the effects of YerkesDodson Law on individuals behaviors, which allows individuals to make behaviors under stressful circumstances. The model can provide diverse individual behaviors, including simulation of pedestrians crossing roads, and terrorist attacks.

Zhang et al. (2017) present an approach for maximizing positive emotional contagion in

crowd evacuation. Safety officers have positive emotions and can calm the crowd down, thereby reducing serious accidents. The approach is as follows:

1. A computational model of positive emotional contagion evaluates how safety officers calm a crowd down. To do so, a trust-based emotional contagion network (T-ECN) and a model of heterogeneous emotional contagion are proposed to manipulate the individual trust relationships and factors for emotional contagion, respectively.
2. A maximization problem of emotional contagion is formulated for agents (including safety officers). The maximization problem is an NP-hard problem. Thus, the optimal positions of safety officers are determined based on an optimization algorithm, such as artificial bee colony.

The T-ECN G(V, *E*) is a directed graph. Each node v ∈ V represents an individual in the crowd. Each directed edge $e(i, j) \in E$ connects node *i* to node *j* and denotes that *j* trusts *i*. An agent *i* is affected by agent *j* when *j* is visible for *i*. The approach formulation for neighboring agents is quite similar to the contagion model. To model how agents affect each other and how a group affects individuals, we should formulate how the agents are linked to each other. After that we can employ optimization techniques to maximize or minimize an objective function. For example, we can place safety officers at proper positions to minimize the overall evacuation time of agents.

We can simulate agents moving in multihazard environments (Xu et al. 2019), such as crowd evacuation in office buildings or regions with terrorist attacks, and pedestrians crossing crossroads with multiple vehicles. The agents affect each other their emotions and decision making.

Conclusion

This entry covers topics on personality, emotion, emotion contagion, personality models, and the applications of simulation techniques on emotional crowd. In general, a crowd simulation system has a physical layer and a decision layer. The physical layer provides information for agents to make proper decision in the decision layer. We also present an approach for modeling emotion contagion in a crowd. It is important to collect neighboring agents of an agent so that we can determine how the agent is affected. The degree of emotion influence on an agent depends on the agent's personality and the surrounding environment. The action taken by an agent can be computed based on the BDI model. Emotional crowd enriches crowd behaviors and has a wide range of applications in games, movies, and disaster simulation. Emotional crowds have been adopted in evaluating task performance of users in virtual reality (Huang and Wong 2018; Volonte et al. 2020).

Cross-References

- ▶ Crowd Evacuation Using Simulation Techniques
- ▶ Crowd Simulation

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Simulations

▶ Gamification and Serious Games
▶ Origin of Virtual Reality

Simulator Sickness

▶ Cybersickness

Single-Player Game

▶ God of War (2018), an Action-Adventure Game
▶ The Elder Scrolls V Skyrim

Singular Point

▶ Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features

Situated Learning

▶ PBL-Based Industry-Academia Game Development Education

Sketch-Based Posing for 3D Animation

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Synonyms

Mocap; Motion capture; Three dimensional; Two dimensional

Definition

Sketch-based posing refers to the automatic posing of 3D models using 2D hand-drawn sketches. It also refers to user interfaces that allow for 3D posing by drawing, instead of operating complex 3D software controls.

Introduction

Animation encompasses entertainment ranging from traditional hand-drawn pieces like *Snow White and the Seven Dwarfs* all the way to cutting-edge visual effects in blockbuster Hollywood films like *Avengers*: *Age of Ultron*. As the boundaries of what is possible are pushed and 3D computer animation is widely adopted, this originally artistic field has become highly technical. Today's animators employ cutting-edge techniques, such as 3D skeleton manipulation and mocap.

This technological boost has helped artists give life to characters and worlds that previously existed only in the realm of imagination. Unfortunately, it has also increased the breadth of knowledge a modern animator is required to have. Classically trained animators may find it even more difficult to transfer their skills to 3D computer animation. To address this issue, researchers have attempted to combine technology with traditional methods. An example of these attempts is to use physical, modular components to build puppets which are then used to animate 3D models (Jacobson et al. 2014). Another example is leveraging the pencil-and-paper skills of traditional animators.

This chapter is an overview of the latter: methods that utilize hand-drawn sketches in order to pose or animate 3D models.

Background

In traditional 2D animation, the artist is drawing the shape of the character while also drawing the movement of the character, conveying very dynamic movement using the 12 principles of animation (Thomas and Johnston 1984). In 3D animation, the shape of the character already exists in the form of a 3D model, and the artist has to deform it using 3D software like Autodesk Maya.

Keyframing is the mainstream method of animating 3D characters, by moving controls on a hierarchical structure, called a rig (e.g., joints on a skeleton). Forward kinematics (Burtnyk and Wein 1976) allow the artist to control the pose by *rotating* joints of the rig. Inverse kinematics (IK) (Zhao and Badler 1994) allow the artist to *translate* joints (e.g., the wrist) of a character to a position in 3D space, and the rest of the body follows to fit a pose.

A 3D rigged model is still the basis for all the methods that are presented in this chapter. The novel aspects of these methods are not in how a 3D character is modeled or rigged, but in how a user can manipulate the character's rig, replacing the mainstream skeleton manipulation process with a sketch-based one.

The first category of sketch-based approaches for 3D animation consists of supervised methods, where a user guides the system through hand-

drawn sketches instead of, e.g., using a mouse. Examples of this *sketch-based interface approach* attempt to extract animated sequences from mocap databases (Xiao et al. 2015) or make use of differential blending for expressive poses (Oztireli et al. 2013).

The second category of methods does not use hand-drawn sketches as an interactive interface but as a way to automatically infer the 3D pose. This category can be further broken down into two subcategories, the *database approach* and the *generative approach*. The database approach uses a database as a knowledge domain, whether it is to position objects in a scene (Xu et al. 2013) or to classify the shape itself (Eitz et al. 2012). The generative approach attempts to pose a pre-existing 3D model until the pose matches the information from the drawing, whether it is to pose animals (Favreau et al. 2006) or humans (Ivekovic et al. 2008).

Common Issues

Posing 3D models from 2D drawings is a complex, open problem which has many commonalities with the original computer vision problem of inferring a 3D pose from 2D images (Gavrila 1999). The problem is therefore under-constrained, as the 2D drawings do not contain sufficient information to extrapolate accurate 3D pose data.

The computer vision problem deals primarily with real photographs, while computer animation is full of fantastic creatures. The anatomical limits of imaginary creatures are often unknown, unlike those of humans. Moreover, a sketch can lack color or contain noise (e.g., in the form of shading). As exaggeration is often used to add dynamism, sketches can be inaccurate in terms of scale.

When dealing with photographic or video data, multiple cameras positioned around the subject can be used to provide multiple viewpoints. For example, it is possible to have a room with cameras on all walls, so that when a person steps in, they are viewed from multiple angles. In contrast, a hand-drawn animation frame would only be drawn with one view angle in mind.

Finally, the *forward-backward* or *depth ambiguity* is a recurring issue. For specific poses, it is difficult to know if a limb is facing forward (toward the camera) or backward (away from the camera). For example, given only the silhouette of a drawn lamp, more than one interpretation exists: the lamp's head could be facing the camera or away from the camera (Fig. 1).

State-of-the-Art Work

In this chapter, three pieces of recent research are singled out and explained in more detail. As an example of the *sketch-based interface approach*, the line of action is used as a user-friendly interface for posing of 3D characters (Guay et al. 2013). Using drawings and minimal user input, a *database approach* example leverages a set of mocap animation sequences to use as a knowledge base (Jain et al. 2009). Finally, an

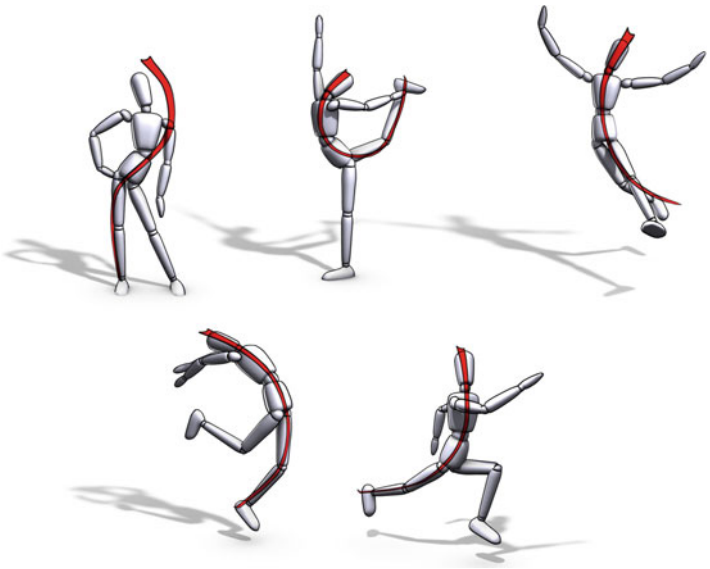
Sketch-Based Posing for 3D Animation, Fig. 1 Example of the depth ambiguity issue in the inferred 3D pose of a lamp

example of the *generative approach* uses global optimization and generates new poses every iteration, until the correct pose is found (Gouvatsos et al. 2014).

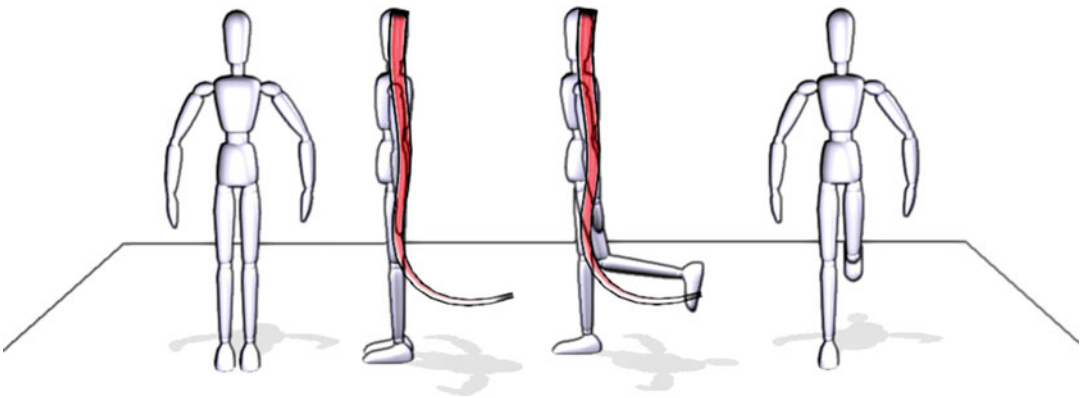
Sketch-Based Interface Approach

The line of action (LOA) is a tool used by animators that helps capture the principal shape and expression of a character in a single line (Fig. 2). These lines are C- or S-shaped 2D curves. In their work, Guay et al. propose a mathematical definition of the LOA. By formulating and solving an optimization problem, they are able to align a 3D character's bones to lines of action that are drawn by the user. The user can view a 3D character from different angles and draw curves on top. For example, a user who wanted to bend a 3D character's knee would look at the character from the side and draw a C-shaped curve, indicating a bent leg (Fig. 3).

The LOA is used to determine the screen space positions and tangents of a subset of the 3D character's bones, which Guay et al. call the body line. The body line is defined as a maximal, connected



Sketch-Based Posing for 3D Animation, Fig. 2 Character poses created by sketching lines of action (Guay et al. 2013)



Sketch-Based Posing for 3D Animation, Fig. 3 Bone rotations are constrained to the viewing plane. The bones are parameterized as a single axis-angle component. The axis is the camera's viewing direction projected onto the floor plane. From left to right is the initial pose, a side view with the LOA, the result after optimization, and a frontal view of the final pose (Guay et al. 2013)

Sketch-Based Posing for 3D Animation, Table 1 Number of strokes and rotations and time taken using lines of action versus using 3D IK widgets in Maya (Guay et al. 2013)

Figure	Num. of strokes and rotations	Time (LOA)	Time (Maya)
Walk	4 strokes 1 rotation	20 s	90 s
S shape	3 strokes 0 rotations	20 s	120 s
Hero punched	6 strokes 2 rotations	90 s	150 s
Hero punch	7 strokes 4 rotations	2 min	3 min 30 s
Animation			
Dancers	6 strokes 1 rotation	30 s	2 min 45 s
Cartoon swing	7 strokes 1 rotation	45 s	2 min 30 s
Muybridge	34 strokes 1 rotation	6 min	22 min

linear chain in a character's skeleton, for example, from head to a foot or from a hand to a foot. As such, a total of ten body lines exists by this definition. The user can manually select the body line they want to manipulate, or they can draw an LOA to select the body line automatically. Once a body line is selected, the best pose is found by solving an energy minimization problem. The difference between the shape of the character's bones in the body line and the shape of the LOA is minimized, using gradient-based local optimization.

The evaluation compares the time it takes to recreate poses with the method by Guay et al. versus the time it takes to recreate the poses with inverse kinematics in Autodesk Maya (Table 1).

Database Approach for Automatic 3D Posing and Animation

The work by Jain et al. introduces an algorithm which takes a set of 2D hand-drawn frames as input. Additionally, a user overlays joints (as dots) on top of the frames and specifies the position of an orthographic camera in 3D space. The algorithm maps the input to a database of mocap information to identify a suitable clip. The clip is projected to 2D and matched to the hand-drawn frames in two ways: timing and exact pose. Finally, the 2D time-aligned and posed result is reconstructed in 3D.

Jain et al. propose a novel pose descriptor to represent 2D poses. This pose descriptor allows for pose comparison while being invariant to translation and scale (meaning it is not affected by changes in translation and scale). Each joint is represented as an angle with respect to a coordinate frame attached to its parent joint. For example, a wrist is represented as the angle between the wrist-elbow bone and a coordinate frame attached to the elbow (Fig. 4). Therefore, a given pose P is a vector of polar angles θ_n:

$$P = [\theta_1, \theta_2 \ldots \theta_K],$$

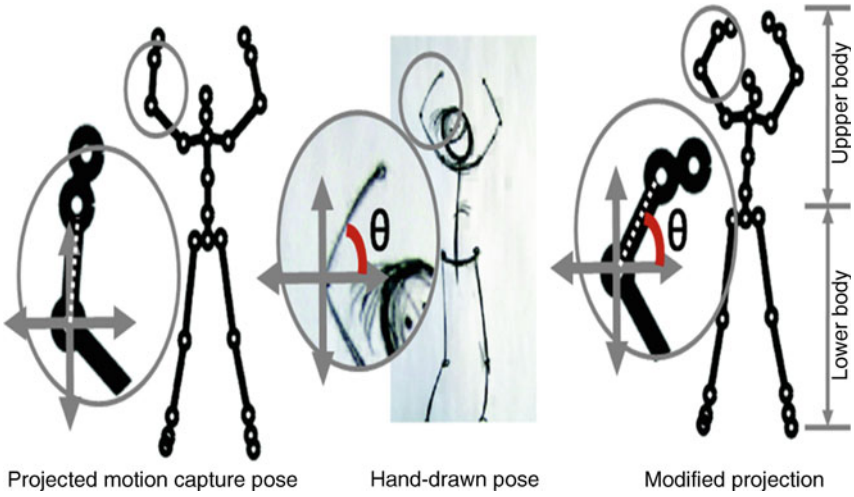
where K is the number of joints pinpointed by the user.

Jain et al. break their algorithm down to three steps. Firstly, the mocap sequence is aligned to the timing of the sketches, using the dynamic time warping algorithm (Sakoe and Chiba 1978). Secondly, the time-aligned mocap segment is projected to 2D and made to best match the pose in the sketches. The 3D projection (projecting a 3D space into 2D) is achieved through the user-specified orthographic camera. To match the pose, each joint is rotated in the image plane until its pose descriptor matches the pose descriptor of the sketch. Thirdly, the missing third dimension is inferred. Jain et al. formulate a linear least squares system to estimate the optimal 3D pose given the time-aligned and fitted 2D pose.

This method is evaluated by animating a ballet dancer, a happy flower, a stylized sneaky walk, and a sequence of jumping jacks (Fig. 5).

Generative Approach for Automatic 3D Posing

Gouvatsos et al. build upon the works of Jain et al. and Ivekovic et al., in order to present a general method for automatically posing 3D



Sketch-Based Posing for 3D Animation, Fig. 4 The pose descriptor consists of in-the-image plane angles for every limb segment (Jain et al. 2009)

models. The proposed method avoids making external assumptions about the 3D model, allowing it to be used on different types of characters (e.g., humans and horses). Similarly with Jain et al., minimal user input is necessary in the form of overlaying the joints over the hand-drawn sketches. Additionally, a camera in 3D space is used to project a 3D pose to 2D. The sketch is compared to a rendered image of the 3D character, using a combination of computer vision descriptors. Different 3D poses are generated and compared until a good match to the sketch is found.

Gouvatsos et al. use three descriptors to compare drawings to renders. The first comparison descriptor is the position of joints overlaid on top of the sketch (Fig. 6). The second descriptor is an edge map extracted with the Canny algorithm (Canny 1986), which represents the internal lines of the drawing (Fig. 7). Finally, the third descriptor is a silhouette of the character, which represents the overall shape (Fig. 8).

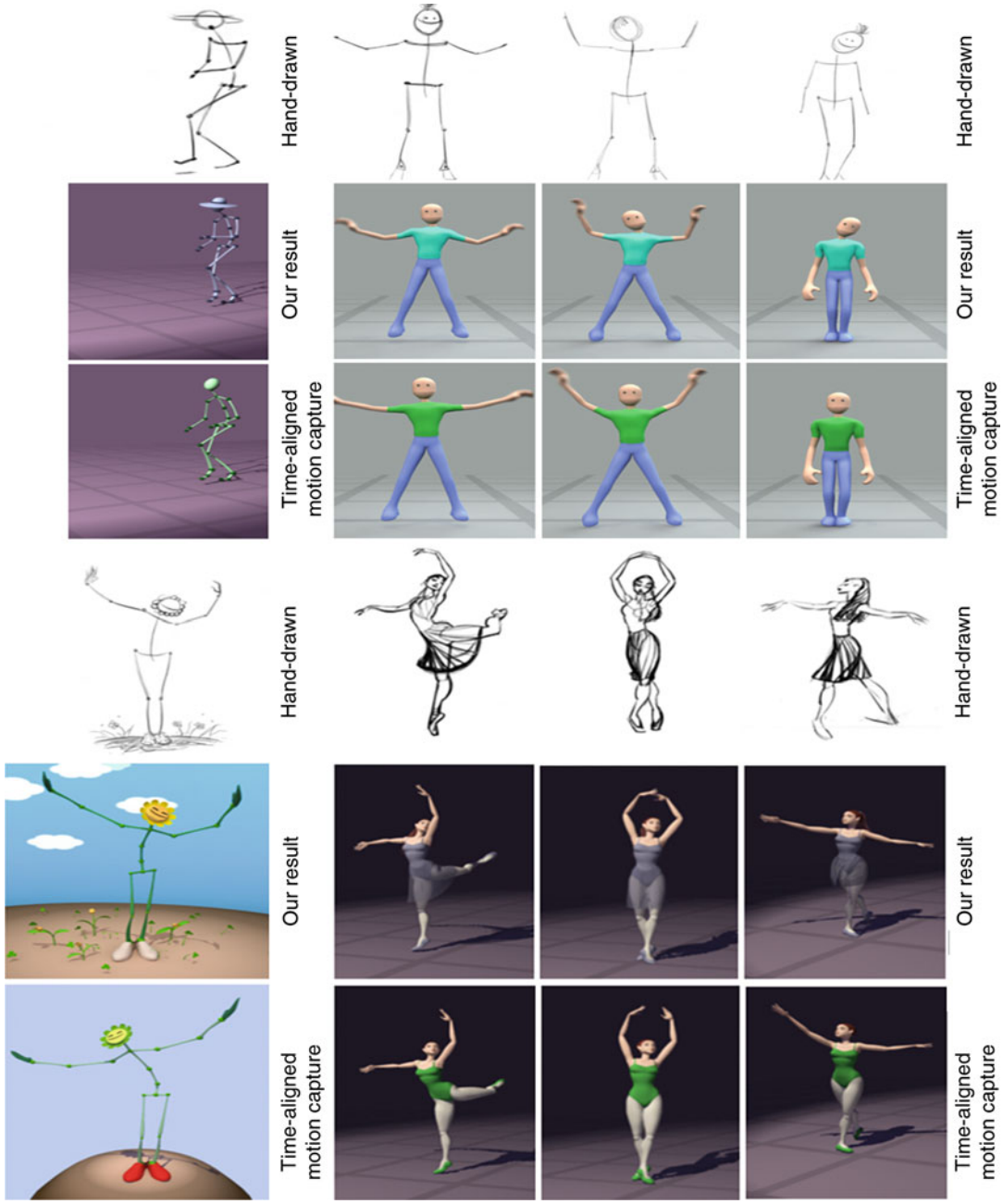
The method proposed is to generate new 3D poses and attempt to minimize the difference between them and the sketch. All the possible poses are seen as a search space of solutions. To navigate that search space, a variation of the particle swarm optimization (PSO) algorithm is used. The difference between the hand-drawn sketch and the 3D pose is represented by an objective function with three terms, one term for each descriptor.

To improve its global search capabilities, the PSO variation is implemented to run on a graphics processing unit. Moreover, a constriction factor and random variation are added in every iteration, to speed up convergence and avoid local minima, respectively.

This method is evaluated by posing a horse (Fig. 9) and a lamp (Fig. 10).

Discussion

Guay et al. present an interesting interface that allows beginners to quickly and intuitively pose 3D characters. However, more detailed, complicated poses are not possible to reconstruct, as the LOA is limited to C- and S-shaped curves. Jain et al. present an automatic posing method that produces impressive results, but the dependence on a mocap database means it is not always an option. Building a database can be expensive, especially for non-humanoid animation. Gouvatsos et al. present an automatic posing method that does not require a database and can be applied to any character. However, it takes



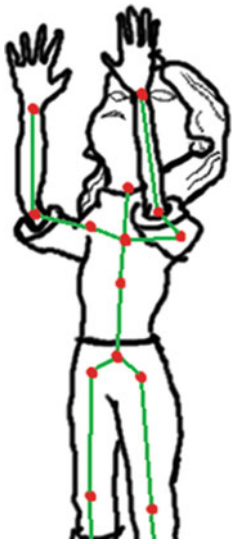
Sketch-Based Posing for 3D Animation, Fig. 5 In all cases, the generated 3D animation matches the hand animation much more closely than the mocap animation (Jain et al. 2009)

longer to run than both other methods and may have less accurate results.

The implementation details of each approach can be studied in the published works. Analyzing them provides insight into patterns that can be used for successful sketch-based 3D posing.

Assuming one is able to formulate a representation for the poses, it is still necessary to match a

Sketch-Based Posing for 3D Animation, Fig. 6 Joints overlaid by a user on top of a drawing



Sketch-Based Posing for 3D Animation, Fig. 8 Silhouette of a drawing

Sketch-Based Posing for 3D Animation, Fig. 7 Edge map of a drawing

3D posed model to the 2D sketch and infer the missing depth. To compare a 3D pose to the 2D sketch, both need to be in the same space. As such, the 3D pose can be reduced to 2D through a camera (e.g., by rendering or using the depth buffer). This camera represents the imaginary camera an artist has in their head when drawing a scene. The missing depth can be inferred through optimization, and all three presented works use an objective function to compare poses.

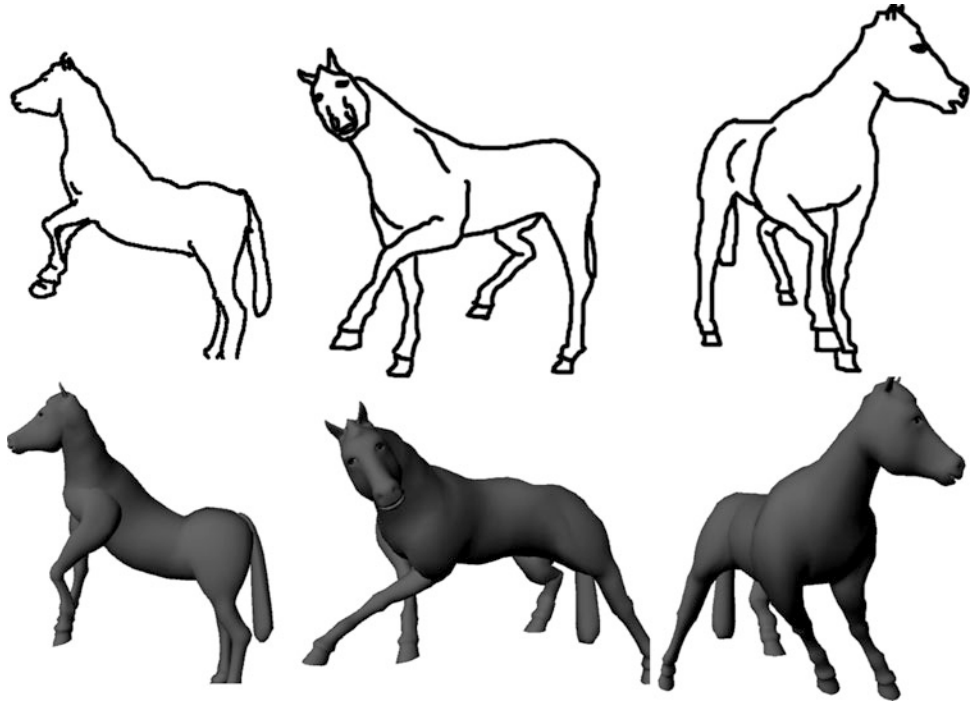
Overall patterns for implementation are deduced by generalizing from the findings of recent works. While these patterns are addressed one by one, they can also be combined depending on the implementer's aim.

Representing and Comparing Poses

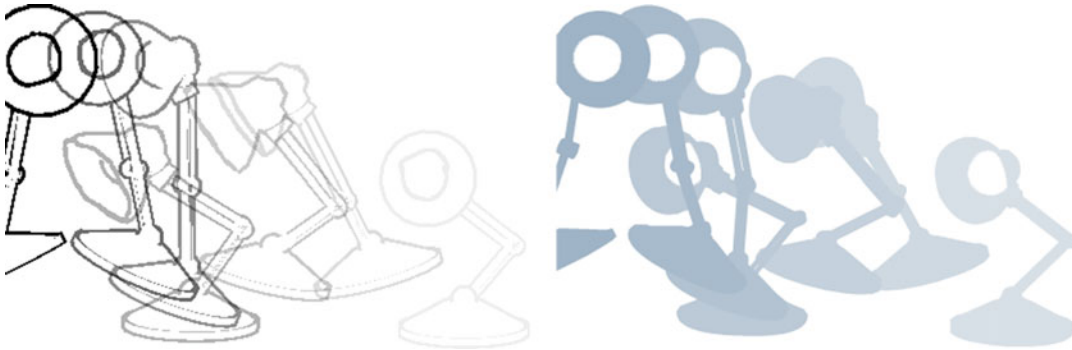
Jain et al. as well as other recent works (Xiao et al. 2015) propose pose descriptors that are translation and scale invariant. This is useful, as two characters with the same pose can have different sizes or be in different positions on the sketch. Descriptors that are not invariant to translation and scale can still be used, assuming that the characters in both the sketch and the 3D projection match (e.g., drawn storyboards that match the 3D scene).

To use various descriptors (e.g., edge maps and silhouettes like Gouvatsos et al.), it is good practice to normalize all values to be between 0 and 1. This way enforces values from different methods to be compared on the same scale.

For example, using joints to describe a pose can be effective, but using only a Euclidean distance to compare two poses is not invariant to translation or scale. To achieve an invariant pose descriptor $P_{\text{invariant}}$, Xiao et al. divide the joint



Sketch-Based Posing for 3D Animation, Fig. 9 Side-by-side comparison of drawings (*top*) and estimated 3D poses (*bottom*), for a horse model



Sketch-Based Posing for 3D Animation, Fig. 10 Side-by-side comparison of a sequence of drawings (*left*) and a sequence of estimated 3D poses (*right*), for a lamp model

distances P, by the overall height of the body H_{body}:

$$P_{\text{invariant}} = \frac{P}{H_{\text{body}}}$$

Jain et al. use a more complex but effective method as described in section "Database Approach for Automatic 3D Posing and Animation."

Supplying a Knowledge Base

The under-constrained nature of the problem can be resolved by viewing the same pose from different angles (Ivekovic et al. 2008). The interface by Guay et al. uses multiple views, as it is applied directly in a 3D environment. However, when only one sketch is available, a knowledge base is necessary to reduce the possible poses. Humans understand a drawn character's pose due to prior

knowledge, e.g., anatomically plausible poses or poses that make sense in context. Enforcing rotation limits on character's joints, assumptions about the type of character (e.g., humanoid), and databases are all suitable knowledge bases.

Restrictions on the 3D character's joints can be set by an artist with good intuition or by using real data (e.g., degrees of freedom of humans). However, for more stylized animation with exaggerations, the restrictions can be distracting for animators.

Making assumptions about the type of character can help reduce the number of possible poses greatly at the cost of reducing the problem cases a method can be applied to. For example, human-specific assumptions would mean that a method can only be applied on humanoid characters.

Databases come with similar trade-offs. For humanoids, mocap databases can be populated cheaply, using devices such as Microsoft Kinect. The data can consist of poses or whole 3D models (Kholgade et al. 2014). However, building comprehensive databases for noncooperative characters (e.g., elephants) is more complicated. Additionally, storing a large database and extracting information from it requires infrastructure and budget that smaller studios may not have.

Optimization Methods

Choosing an optimization method depends on how the problem is formulated. Jain et al. formulate the problem as a linear least squares system. Their algorithm is fast but only works with an orthographic projection. Gouvatsos et al. choose the particle swarm optimization algorithm, a global optimization method which makes no assumptions about the problem. Although the PSO scales well when parallelized on more powerful hardware, it is slower.

In all three cases, there is one common parameter: an *objective* or *energy* function. This function takes into account the chosen descriptors and transforms them into values that can be minimized. Guay et al. measure the difference in terms of positions and tangents of the bones. Jain et al. measure three terms: projection error, limb length error, and mocap regularization term. Gouvatsos et al. use a weighted combination of all pose descriptors:

$$f = w_1 D_j + w_2 D_s + w_3 D_e,$$

where D_j, D_s, and D_e are the differences in terms of joint distance, silhouette, and edge map, respectively. The weights w_1, w_2, and w_3 can be set to $\frac{1}{3}$ to have all descriptors contribute equally. Choosing and constructing this objective function is crucial and has to be done together with the design of the pose descriptors.

Sketch-Based Methods in Real Pipelines

Despite limitations in terms of possible poses and accuracy of results, production pipelines can still benefit from sketch-based methods. Final animation may still need the hand of an artist, but time and effort can be saved. Semiautomatic methods from Jain et al. and Gouvatsos et al. require little user input and allocate heavy work to the machine. Even if the accuracy of the results is not production ready, these methods can still serve as an automatic first pass for artists to build on.

The user input itself can take place during a cleanup pass of the drawings. Removing the user input completely would make these methods even more attractive, and future work can look into using medial axis methods to achieve this (Abeysinghe et al. 2008).

Moreover, combining all approaches together in one system could lead to a promising hybrid with most advantages and least disadvantages of all the methods.

Cross-References

- ▶ 3D Room Layout System Using IEC (Interactive Evaluational Computation)
- ▶ Abstraction and Stylized Design in 3D Animated Films: Extrapolation of 2D Animation Design
- ▶ Genetic Algorithm (GA)-Based NPC Making
- ▶ Meta Artificial Intelligence and Artificial Intelligence Director

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Skill System

► ROP-Skill System: Model in Serious Games for Universities

Skill Tree

► ROP-Skill System: Model in Serious Games for Universities

Skull

► Skull and Roses Card Game

Skull and Roses

► Skull and Roses Card Game

Skull and Roses Card Game

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Synonyms

S&R; *Skull*; *Skull and Roses*

Definition

The *Skull and Roses* (also known simply as *Skull*) is a multiplayer card game with small stochasticity, imperfect information, and partially observable outcomes. Consequently, like in the case of poker, it requires to mix bluffs, opponent modeling, and coalitions as high-level strategic plays, achieving all this with a very simple set of rules and elements.

Notation

There are four main parameters in *Skull and Roses* to be considered: the *number of players* P, the *initial number of skulls* $S = 1$, the *initial number of roses* $R = 3$, and the *number of wins* (successful challenges) required $W = 2$.

The original game has $3 \leq P \leq 6$, and the expansion – *Skull and Roses RED* – allows up to $3 \leq P \leq 12$.

History

It was created by Hervé Marly, illustrated by Rose Kipik, and edited by *Lui-même* in 2010. After that, the game gains its popularity very quickly, being officially published in German, French, and English. The game received the international price of as *d'or*, *jeu de l'année*, *Cannes 2011*.

This game is also known for the surprising fact that it took its designer, Hervé Marly, "15 years of perseverance" to properly balance it (Marly 2012).

Game Rules

A canonical game consists in a series of rounds composed by several turns; this decomposition is specified by the following rules (Marly 2012):

Game sequence:

1. Play a round.
2. If the last challenger is still playing, he takes the initiative.
3. If the last challenger is not playing, the next player, (*challenger* + 1) mod P, takes the initiative.
4. Repeat until winning condition is reached.

Round sequence:

1. *Do one First turn*.
2. Until a challenge is set, every player in clockwise order does either a *Card turn* or set a challenge, starting by the player that has the initiative.
3. Every player in order do either a *Bet turn* (aiming to become the challenger) or pass (definitively), until the challenger (player with the maximum final bet) is decided.
4. The challenger does a *Revelation turn*, until a skull is revealed or the number of roses revealed matches his own bet.
5. Let w_p be the number of games that challenger p has won so far. If the challenge is successful, increase w_p by one. Otherwise, do a *Discard turn*.

Turns:

- *First turn*: Each player places simultaneously a card in his own pile from his hand.
- *Card turn*: Place a card on the top of your pile from your hand.
- *Bet turn*: Increase the current bet.
- *Revelation turn*: If your own pile is not empty, turn up the top card of your own pile. Otherwise, turn up the top card of any player's pile.
- *Discard turn*: If the revealed skull is your card, choose a card to discard by yourself from your cards. Otherwise, let the owner of the revealed skull choose one of your cards to discard randomly. For both cases, the players other than you do not know which card was removed.

Conditions:

- *Starting condition*: Each player has three roses and one skull and zero win. And Player 1 takes the initiative.
- *Winning condition*: Either winning two challenges or being the last player standing.
- *Successful challenge*: The challenge is successful, if the challenger revealed a number of roses equal to the bet without revealing a skull.

Skull and Roses Card Game, Table 1 The upper bound of state-space size for all possible player values in *Skull and Roses RED*

#Players	3	4	5	6	7	8	9	10	11	12
Upper bound	10^{13}	10^{16}	10^{20}	10^{24}	10^{27}	10^{31}	10^{34}	10^{38}	10^{42}	10^{45}

- *Unsuccessful challenge*: The challenge is unsuccessful, if the challenger revealed a skull in the process of the challenge.

Game Complexity

In order to measure the complexity of a game, there are two well-known complementary approaches: the computational complexity one, given by the complexity class; and the combinatorial game theory one, given by the state-space, game tree, average game length, and average branching factor.

Complexity Class

Skull and Roses is a polynomially bounded game, where resources (hand cards) are used up, and is also a game of imperfect information (each player's hand and pile status).

According to standard book in the field by Hearn and Demaine 2009, the natural extension (parametrization of the number of players, wins, skulls, and roses) of games with these two key characteristics, the two-player version of the game is in *PSPACE*, while the *N*-player version is in *NEXPTIME*. There are proofs to show that many games with those characteristics are in *PSPACE – complete* and *NEXPTIME – complete*, respectively, but the proofs for *Skull and Roses* remain unknown.

State-Space Complexity

The state-space complexity deals with the total number nodes in the game's state graph; this is given by the number of variables needed to fully represent a game-state and their domain sizes.

The upper bound below for the natural extension of the game was proven in Gragera et al. (2013) by bounding the variables in each individual turn (Table 1):

Game-Tree Complexity

$$Size(\text{State} - \text{space}) \leq P^2(R+S)^2 \cdot \left[R + 2 + (R+1)^{P-1}\right] \times \left[4(S+1)^2(R+1)(W+1)\binom{S+R}{S}\right]^P$$

.

The game-tree complexity considers the size of the game tree, a directed graph whose nodes are positions in a game and whose edges are the moves that were played between them. The size of this tree is measured by the number of leaf nodes in the game tree rooted at the game's initial position. This value is equivalent to the total number of possible different games that can be actually played.

An upper bound for the tree size of a single round was given in Gragera et al. 2013 (Table 2):

$$Size(\text{Round tree}) \leq \#placements \cdot \#bets \cdot \#revelations.$$

And a very naive and loose upper bound was also obtained for the full game tree simply by using this bound (with the first-round values) for all possible rounds (without considering the Discard turn):

.

$$Size(\text{Game tree}) \leq (\#Placements \cdot \#Bets \cdot \#Revelations)^{\#Rounds}$$

Skull and Roses Card Game, Table 2 The upper bound of a single round tree size for all possible player values in *Skull and Roses RED*

#Players	3	4	5	6	7	8	9	10	11	12
Upper bound	10^{10}	10^{17}	10^{25}	10^{33}	10^{41}	10^{50}	10^{60}	10^{70}	10^{80}	10^{90}

Skull and Roses Card Game, Table 3 The average length of a game and the average branching factor for all possible player values in *Skull and Roses RED*

#Players	3 players	4 players	5 players	6 players	7 players
Avg. game length	58	130	244	409	633
Avg. branching factor	5.262	9.175	14.445	21.868	32.897
#Players	8 players	9 players	10 players	11 players	12 players
Avg. game length	922	1,282	1,720	2,242	2,856
Avg. branching factor	50.119	78.320	126.218	209.773	358.761

Average Game Length and Branching Factor

The game length is the number of position of each game, the depth of the tree, while the branching factor is the number of children at each node, the outdegree. Both higher branching factors and higher game lengths make search algorithms computationally more expensive and ineffective, due to the exponentially increasing number of nodes and the so-called horizon effect (Table 3).

The previous averages were calculated based on the data collected by 10^7 games played by uniform random players (Gragera et al. 2013).

Future Directions

These conditions make it very attractive as a test-bed for game AIs in the big picture versus quick profit dilemma as well as a good candidate to be included in general game playing test frameworks and competitions (Genesereth et al. 2005).

Due the novelty of the game, still several important problems remain open, being the two most important to find a not naive game tree upper bound and to prove its exact complexity classes.

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Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring

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Synonyms

Calibration thermal imaging; Physiological monitoring

Definition

The accurate and robust ROI detection and tracking in thermal faces can lead to better physiological monitoring. The calibration between RGB-D and thermal cameras allows fee body movements in practice, helping to achieve such goals. This article presents two smart schemes to make the chessboard pattern with black and white squares visible to both cameras during the calibration process.

Introduction

The thermal infrared sensor (Gade and Moeslund 2014) is capable of recording small facial temperature variations because of its high sensitivity to thermal radiations emitted from the skin. Compared with traditional contact and wearable devices (Park et al. 2008; Storck et al. 1996), the thermal imaging process can be carried out in a contactless and unobtrusive way without discomfort. More importantly, the collected thermal data can be used to measure the physiological parameters such as the body temperature, respiration rate, and heartbeat rate. Thus, thermal imaging makes continuous health monitoring of human beings convenient and comfortable but not noticeable, especially benefiting the neonatal infants, children, and elderly people.

Many approaches have been proposed for the physiological monitoring based on thermal imaging (Al-Khalidi et al. 2011; Chauvin et al. 2016; Chekmenev et al. 2007; Fei and Pavlidis 2010; Garbey et al. 2007; Murthy and Pavlidis 2006). The first key step is to identify the regions of interest (ROIs) like forehead, nose, mouth, cheeks, ears, and neck from the detected face, and track them in each frame image appropriately. Usually, the mean thermal signal of the nostril region carries the breathing information, and the average temperature change along the superficial blood vessel in the neck area reveals the heartbeat information. The accurate and robust segmentation of these ROIs is crucial to the overall performance. The main challenge comes from the head movements of the subjects. In most previous works (Alkali et al. 2013; Chauvin et al. 2016; Chekmenev et al. 2006, 2007; Fei and Pavlidis 2010; Murthy and Pavlidis 2006; Sun et al. 2005; Yang et al. 2008), the subjects were instructed to stay still during the course. However, they usually exhibit small head motions. More practically, large movements can often be found.

To overcome the inaccuracy caused by small movements of the subjects, Fei et al. (2005) applied a tracker based on iterative image registration (Lucas and Kanade 1981) to the nasal tip area. Aiming at automatically following the breathing signal, a robust and stable Bayesian tracker utilizing the mean shift localization (MSL)-based (Fukunaga and Hostetler 1975) particle filtering was proposed in (Zhu et al. 2005). This tracker can cope with significant head movements, but it fails in the scenario that more than one window of the tracking ROI is lost or blocked during the process. In addition, the particle filtering is computationally expensive. In (Fei and Pavlidis 2010; Murthy et al. 2009), the authors adopted the coalitional tracking algorithm (Dowdall et al. 2007) to deal with the subject's motion during the breathing measurement. It employs a cluster of collaborative particle filter trackers and optimizes the multitracker interaction through game theory to gain both accuracy and robustness. It is worth noting that the behavior of the coalitional tracker is not absolutely deterministic due to the stochastic components of the particle filter trackers. The nostril ROI is then extracted by conducting integral projections on the edge image obtained from the original thermal face image applying a 3×3 Sobel edge detector. The leftmost and rightmost maxima of the vertical integral projection generate the respective left and right outer edges of the nostril, and the peak of the horizontal integral projection produces the nostril's base edge.

To actively track the mouth-nose region, Chauvin et al. (2016) modified the tracking, learning, and detection (TLD) predator approach (Kalal et al. 2010) to make it adaptive to the thermal data. With a manually initialized ROI, the TLD algorithm produces the coordinates and

size of the bounding box for each frame using a minimum set of features. If the tracker module loses the ROI, the detector module will reinitialize the tracker with a new bounding box obtained by an exhaustive search using a sliding window method. Therefore, this technique can handle relatively large head movements. Similarly, they implemented the 3 × 3 Sobel operator to extract the contours of the mouth-nose ROI and then yielded the mask by setting all the pixels with a gradient value less than the specified threshold to zero. The ROI is attained by employing the mask operation on the contour image.

Yang et al. (2008) manually initialized a region for the first frame, which is then divided into a series of nested regions (R^i) based on an incremental temperature step (ΔT) and a reference temperature (T_{ref}) which is the mean temperature of all the pixels on the bounding box of the initialization region. By selecting the optimal threshold ($T^* = T_{ref} + i^*\Delta T$) that makes the area of region R^i* drop sharply against the area of region R^i*-1, the ROI of the first frame is chosen as the region with largest connected component in R^i*. Correspondingly, the ROIs of the subsequent frames are attained by employing the same T* to compute the isotherm and tracking the contour utilizing energy minimization.

In practice, traditional thresholding (e.g., Otsu's adaptive thresholding [Alkali et al. 2013, Lampo et al. 2009, Murthy and Pavlidis 2006]) and edge detection (e.g., Prewitt operator [Al-Khalidi et al. 2010, 2011, 2015]) are also widely used for the ROI segmentation. In some investigations (Alkali et al. 2014; Garbey et al. 2007; Sun et al. 2005), the ROIs are even manually placed to ensure the high accuracy of segmentation, which is time consuming and susceptible to subjective errors.

Ideally, the person under estimation should be able to move around without constraints. To cope well with such free head movements, this article introduces the calibrate method integrating the thermal sensor with the RGB-D sensor to produce more reliable ROI segmentation results, taking advantage of the RGB-D imaging in face detection and landmark points extraction.

Approaches

Most of previous approaches for measuring the physiological data generally work under certain environments such as temperature-controlled room, subjects sitting comfortably in a chair (remaining still or with small movements), facing to the camera, and within a specific distance from the camera. Sudden temperature changes and body movements are the main challenges to the physiological monitoring. Although researchers investigated different methods (Al-Khalidi et al. 2011; Alkali et al. 2013, 2014; Chauvin et al. 2016; Fei and Pavlidis 2010; Garbey et al. 2007; Murthy et al. 2009; Murthy and Pavlidis 2006; Sun et al. 2005; Yang et al. 2008) to alleviate small head motions of the subjects, large or free head movements in real applications are still a major factor affecting the overall accuracy. The direct segmentation of the thermal images using thresholding and face landmark points detection applying the Dlib algorithms (King 2009) usually produces results with noises. To accurately evaluate the facial temperature evolution of the subjects, a RGB-D camera can be potentially utilized to guide the localization of the ROIs in the thermal data. This necessitates a stereo calibration between the thermal and RGB-D sensors using a chessboard pattern with black and white squares.

As illustrated in Fig. 1, the thermal and RGB-D sensors are mounted on top of a robot at 1.3 m and 1.1 m from the floor, respectively. The comfortable distance between the robot and the subject is about 1.0 m. The chessboard can be easily detected by the RGB camera; however, the black and white squares cannot be differentiated by the thermal camera as their heat radiations are more or less the same. To make the chessboard pattern visible to both sensors during the calibration process, Zhao et al. (2018) designed two smart schemes.

Calibration Using Combined Chessboard

The 8 x 6 chessboard pattern with 23.5 mm black and white squares is used for the calibration, where all the black squares in a thick white cardboard of A4 paper size are first removed, and then

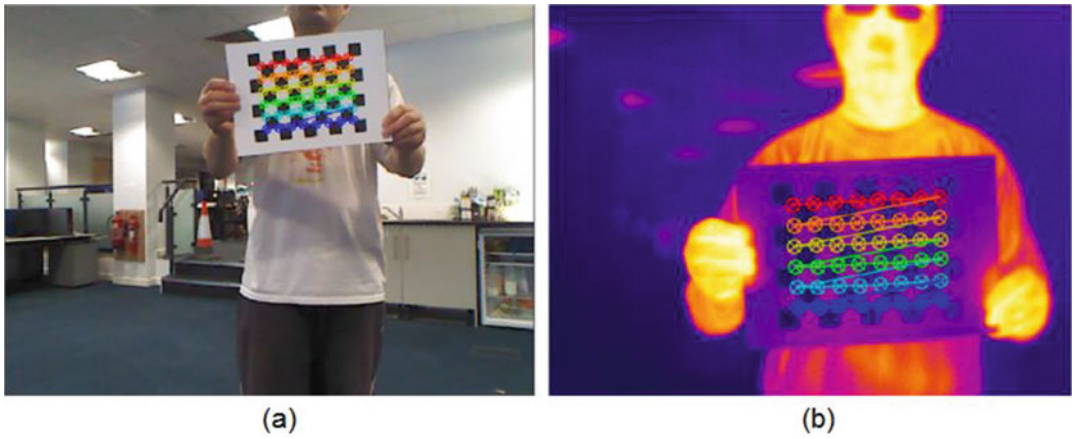
Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 1 RGB-D and thermal sensors mounted on top of a robot

heated using a 300 W incandescent lamp for several minutes (see Fig. 2). At the same time, a thin black sheet of the same size is cooled down in a fridge for a few minutes to bring it to a low temperature. The two sheets are then combined together so that both cameras can see this black and white chessboard pattern, as the white cardboard and black sheet appear as white and warm, and black and cold in the RGB-D camera and thermal camera, respectively (see Fig. 3).

Calibration Using Electrically Heated Chessboard

The combined chessboard is visible to the thermal camera for at most 5 minutes as the temperature difference between the white cardboard and black sheet diminishes, and the operation procedure is not very convenient. Sometimes, the heating and cooling processes need to be carried out twice for one calibration. Each time before calibration, it also takes some time to finish the heating and cooling. To overcome these shortcomings, an electrically heated chessboard was designed (Zhao et al. 2018), which consists of a 3 mm black acrylic sheet at the back and a 1.5 mm bicolor (black on

Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 2 Lamp for heating the white cardboard



Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 3 Calibration of the RGB-D camera and thermal sensor using a combined chessboard. (**a**) Detected pattern in RGB image and (**b**) detected pattern in thermal image

white) laminate sheet at the front. The chessboard pattern is manufactured by precisely carving the black squares using a laser cutter. Each corner of the white and black squares is then associated with a resistor. When the power is on, the resistors emit radiations, which can be detected by the thermal camera, as depicted in Fig. 4.

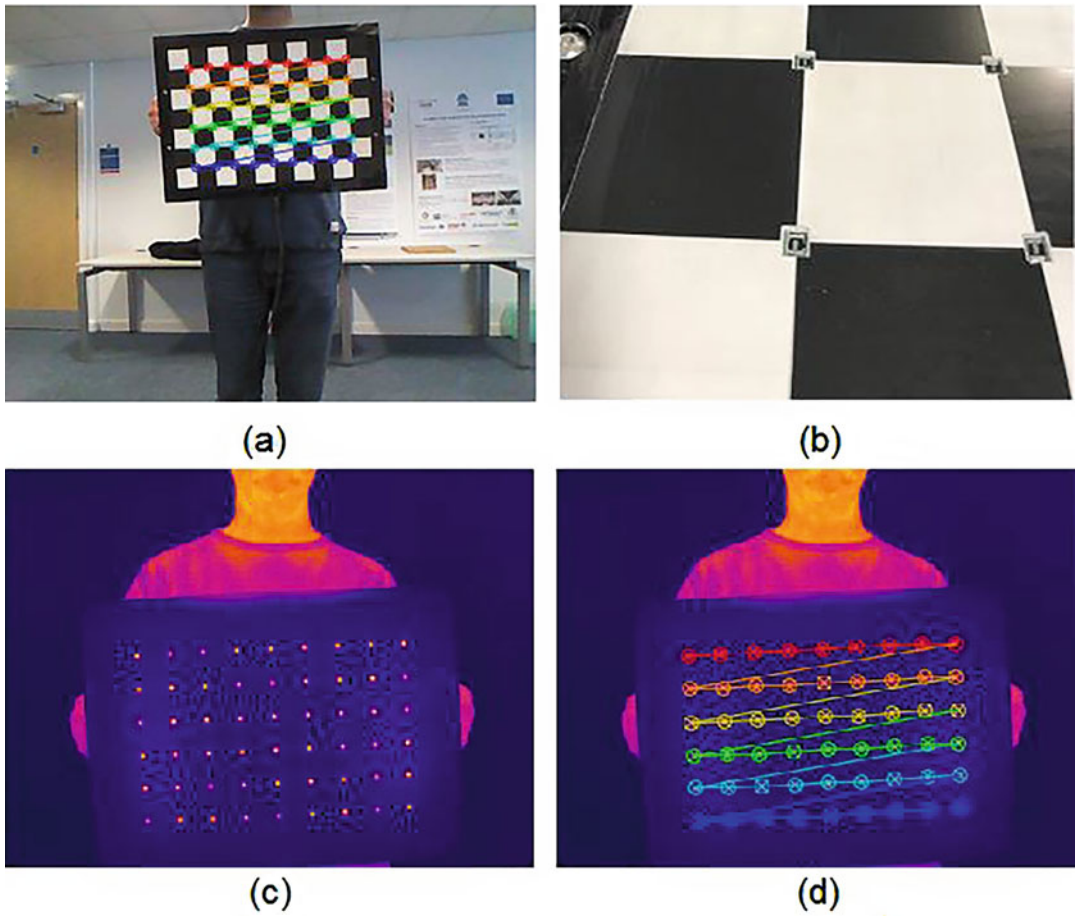
In comparison with the combined chessboard, the calibration procedure by this pattern can be conducted immediately after turning on the power. Moreover, the resistors can be heated for a much longer time, enabling to perform multiple calibrations continuously. It is worthy to note that the resistors may be overheated after too long time (e.g., more than 30 minutes), which could affect the calibration results.

Performance Evaluations

As demonstrated in Fig. 1, the RGB-D camera used in the experiments is Microsoft Kinect V1 (2018) with an 8-bit RGB resolution of 640 × 480 pixels and an 11-bit monochrome depth of the same resolution. Its frame rate is 9–30 Hz. The higher the resolution, the lower the frame rate. In addition, the sensor has a practical distance ranging from 1.2 m to 3.5 m, and an angular field of view (FOV) of 57° (horizontal) and 43° (vertical). Meanwhile, the employed thermal sensor is Optris PI 450 (2018), which has a high sensitivity to temperature (0.04 °C) and an image resolution of 382 × 288 pixels. Its frame rate ranges from 27–80 Hz. The sensor lens has a relatively narrow FOV and a fixed focus length (38° horizontally and 29° vertically with 15 mm lens).

It takes about 3–5 minutes to complete the calibration process, where 80 or 150 sets of 48 corner points are recorded. Based on the pinhole camera model, the intrinsic parameters of both cameras together with the rotational and translational transformation between cameras are estimated via stereo calibration. Face detection and landmark points extraction in the RGB images are obtained by utilizing the Dlib machine learning toolkit (King 2009) based on the histogram of oriented gradient (HOG) features (Dalal and Triggs 2005). Since the target person is assumed not to move significantly between two consecutive frames, the face detection task is performed in a local window corresponding to the face previously detected, thus speeding up the detection process. If this cannot be done, the face detection is carried out completely in the new frame image.

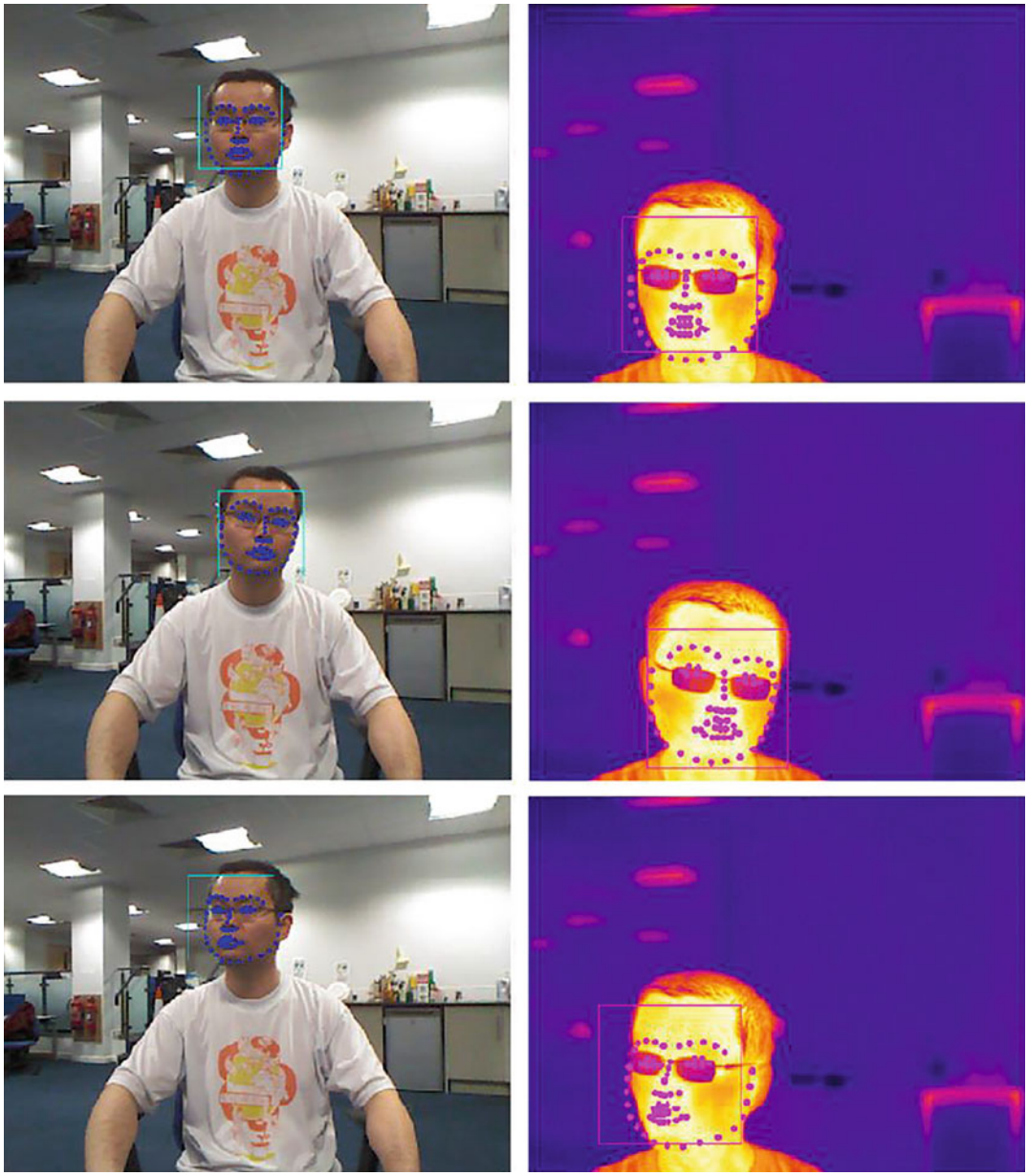
As a consequence of the calibration process, the translation vector and rotation matrix are utilized to map the detected face and landmark points in the RGB image to the corresponding thermal



Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 4 Calibration of the thermal camera with the RGB-D sensor using an electrically heated chessboard. (**a**) Detected pattern in RGB image, (**b**) resistors for heating the chessboard, (**c**) thermal image of the heated chessboard, and (**d**) detected pattern in thermal image

image (see Fig. 5). It can be seen that the person can move around freely and the calibration results are very encouraging. The robust detection results in the thermal data lead to accurate ROIs, which will produce much better physiological measurements.

As described in Fig. 6, the facial ROIs (forehead, nose, and cheeks) in the thermal image can be properly located with respect to the calibrated landmark points. For instance, the forehead center can be considered as the middle of the two eyebrow corner points. Accordingly, the average temperature in the forehead area is computed as the body temperature. The evolutions of the mean temperature in the nose and cheek areas along the timeline are used for the measurement of the respective respiration and heartbeat rates applying harmonic analysis. Figure 7 displays an example of the physiological monitoring results by fast Fourier transform (FFT) (Chauvin et al. 2016; Garbey et al. 2007), where the dominant frequency with the highest peak magnitude in the temperature signal's spectrum is identified, and then multiplied by 60 to obtain the respiration or heartbeat rate in cycles per minute. Compared with the ground truth data obtained by a contact thermometer and a wearable oximeter, the calculated body temperature error is within 1 °C, and the estimated respiration rate of 15 breaths per minute

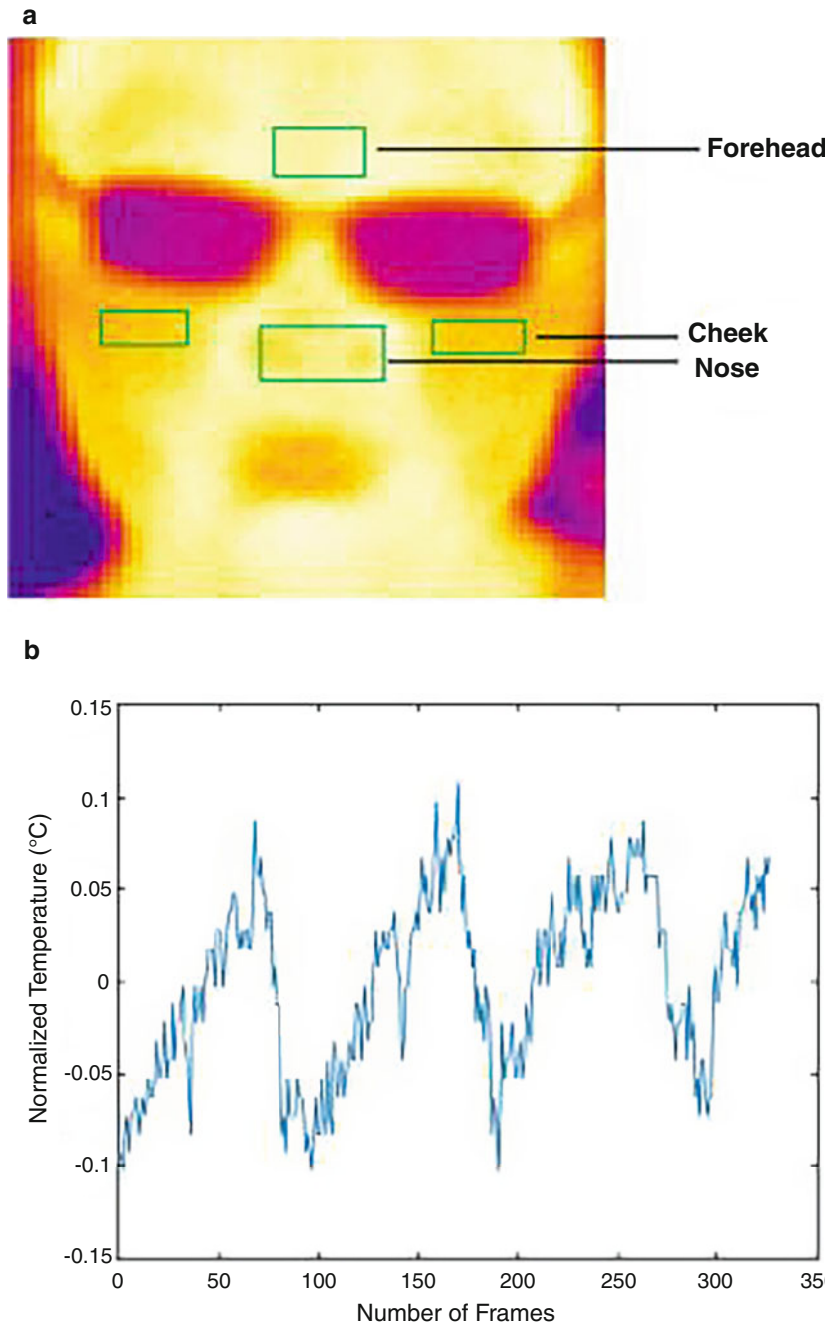


Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 5 Calibration results overlaying on the RGB and thermal images in three orientations

(BPM) is accurate, while the measured heartbeat rate of 95 beats per minute (BPM) needs to be further improved. It was explained that the relatively big bias of the heartbeat is because of its larger variation range than that of the respiration, and it can be reduced by denoising the input temperature signal (Zhao et al. 2018).

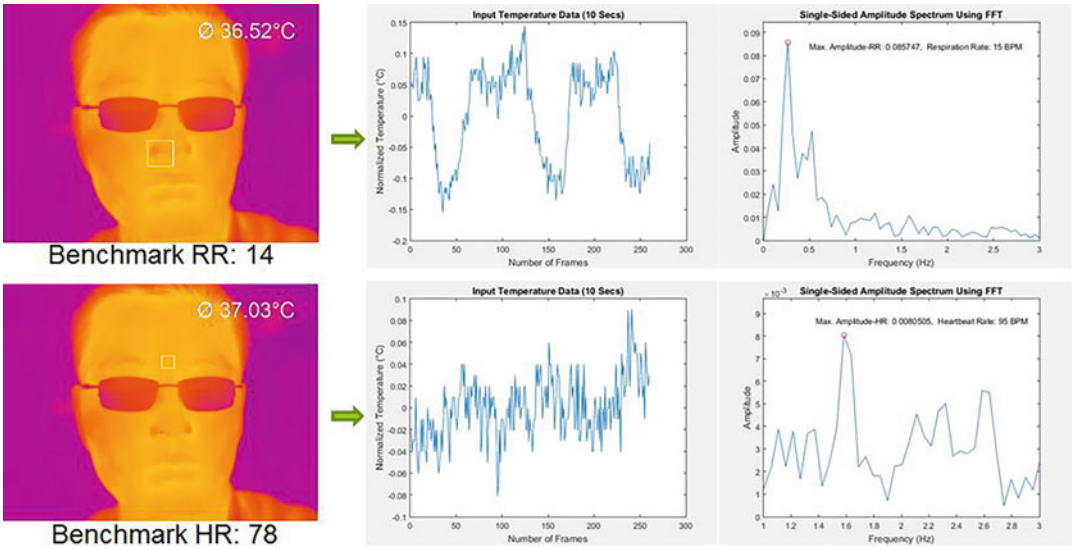
Discussion

During the calibration, two conditions need to be satisfied: i) both cameras detect a complete chessboard and ii) all the corner points on the chessboard can be identified by both cameras. In presence of more than one subjects, the calibration



Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 6 Physiological monitoring. (**a**) Facial ROIs and (**b**) normalized temperature signal of the nose ROI

procedure can still be done, as demonstrated in Fig. 8. Furthermore, the calibration approach can address the issue of prohibiting subjects from wearing glasses mentioned in many existing methods (Al-Khalidi et al. 2010, 2011, 2015; Zhu et al. 2005). Nevertheless, it was noticed that the calibration can only be successful when the chessboard is placed within an effective



Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 7 Measured body temperature, respiration rate (RR), and heartbeat rate (HR) from different facial ROIs based on 10 s thermal data

Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 8 Calibration process in presence of multiple subjects

S

distance range of 60–90 cm because of the different FOVs of the two cameras, especially the limited FOV of the thermal sensor. This means that many adjustments have to be conducted to match the FOV of the thermal camera with the other RGB camera (Kinect V1 in this article). In practice, having a motorized pan-tilt unit (PTU) to mount the two cameras could help with this difficulty.

Another reason is that the lens of the thermal camera has a fixed focus length, which means that the acquired image is very clear at a specific distance range, but becomes a bit blurring outside of this range. For average temperature measurement within a ROI, it is not really a problem since it already acts as a low-pass filter, but this could be an issue for extracting a very small feature (e.g., chessboard corner points) on a wide range of distance. Since high-cost thermal cameras with lens of adaptive focus lengths are available on the market, this problem can be alleviated.

To speed up the calibration, a chessboard with bigger square size (e.g., 6 × 3 with 35.0 mm squares) can be implemented. Particularly, it is

Smart Calibration Between RGB-D and Thermal Cameras for ROI Detection and Tracking in Physiological Monitoring, Fig. 9 Deviations of the mapping face landmark points on the thermal images when the subject moves (**a**) backward and (**b**) forward

more convenient and faster to complete the calibration procedure using the combined chessboard. Moreover, the range of the effective distance between the chessboard and the sensors is enlarged to 70–150 cm. Additionally, the frame rates of the RGB and thermal cameras may not coincide with each other. However, this will not greatly influence the ROIs detection and tracking, as the subjects usually keep still within a very short period of time. Thus, the same calibration results are valid for a few consecutive frames. In real applications, this can also be used to accelerate the calibration process.

Due to the narrow FOV and fixed focus length of the thermal sensor, the effective distance between the subjects and the cameras for physiological monitoring after calibration is within a limited range as well. For the 8 × 6 chessboard, it is about 1.0 m. In case that the 6 × 3 chessboard is used for calibration, this distance becomes 1.0–1.1 m. For both cases, the subject's moving forward or backward from the sensors will make the calibration results on the thermal data shifted (see Fig. 9). This problem can be solved by keeping the distance between the subject and the cameras through robot navigation, or employing a costly thermal sensor with multiple lens.

Conclusion

With the advent of portable and affordable thermal cameras of high performance (e.g., FLIR ONE 2018; Seek CompactPRO 2018) that can be easily attached to smartphones, thermal imaging is becoming more and more popular and it

plays an important role in contactless physiological monitoring. Taking advantage of both the RGB-D and thermal imaging, the calibration approaches can tackle large or even free head movements occurring in thermal-based measurements of physiological parameters. It was reported that the calibration of thermal sensor with RGB camera is feasible and the two calibration strategies introduced in this article can benefit the ROIs segmentation and tracking, thus leading to more promising estimation results. To further improve the calibration accuracy and finally produce better physiological monitoring results, it is worthy to apply the circle-pattern chessboard instead of traditional square-pattern chessboard.

Cross-References

► Eye Tracking in Virtual Reality

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Smart Connected Toys

► Smart Toys

Smart Toys

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Synonyms

Smart Connected Toys

Definition

A smart toy is defined as a learning or play device consisting of a physical toy embodiment with electronic components that connects to a computing system with online services through networking and sensory technologies to enhance the functionality of a traditional toy.

The Concept, Phenomena, and Key Principle

A smart toy is defined as a learning or play device consisting of a physical toy embodiment with electronic components that connects to a computing system with online services through networking and sensory technologies to enhance the functionality of a traditional toy. It is an entity built to talk, learn, remember, and respond to a child's request. A smart toy in this context can be effectively considered a computing device or peripheral called smart toys. Smart toys carry both novel and industrial challenges with technical and sociotechnical issues as well as compelling computing technologies in Cloud-connected smart toys. The smart toy is a new cross-discipline research topic in computer science, information systems, and social sciences. Some examples of smart toys include Mattel's Hello Barbie, CogniToys' Talking Dino, and Fisher-Price's Smart Toy Bear. United Kingdom-based Juniper Research has reported that smart toys and related applications are the new key market for toy companies and the sales of smart toys would grow from $2.8 billion in 2015 to $11.3 billion by 2020.

Historical Parts: Landscape

A toy is an item or product intended for learning or play, which can have various benefits. Toys have been part of every culture, as a uniquely designed product for learning, socialization, leisure, and play and intended to benefit children as they go through various developmental stages. Children use toys to discover their identity, learn causes and effects, explore relationships, and practice skills. Children's toys have become increasingly sophisticated over the years, with a

growing shift from simple physical products to toys that engage the digital world as the Internet of Things (IoT). Toy makers are seizing this opportunity to develop products that combine the characteristics of traditional toys such as dolls and stuffed toys with computing software and hardware called Smart Toys. Toy makers have embraced modern technologies such as mobile technology into the design of their products, reshaping the concept of toys (Hung 2015)

Results, Procedures, Processes, Methodology, and Historical Parts

Toy makers such as Hasbro and Mattel have released toys that integrate with networking and sensory capabilities to allow them to detect and interact with their environment. A smart toy works through some form of connectivity (either Bluetooth or WiFi) and can download software and conduct activity through WiFi to a connected source in the Cloud (Tang and Hung 2017). This introduces a service-oriented architecture (SOA) approach between the toys (service providers) and children (service requestors). In general, there are three properties of a smart toy: (1) pervasive, a smart toy may follow the child through everyday activities; (2) social, social aspects and multi-player are becoming a mandatory aspect of interactive smart toys in a one-to-one, one-to-many, and many-to-many relations (Tath 2006); and (3) connected, smart toys may connect and communicate with other toys and services through networks. For example, CogniToys' Dino can listen and answer questions raised by children by voice because the Dino connected to the IBM Watson's Knowledge called Elemental Path's "Friendgine," which a kid-friendly database at the backend is. The integration of smart toy with functionalities, which allows collection, storage, transmission and processing of play information, and generated context data is essential and providing the required interactivity of the smart toy. Smart toys are evolving with continuous feature sets and integrating new technology, which allows players to be more interactive, and individualized with personal preferences. In smart toys, the fusion of data from cameras and sensors allow for a more comprehensive and non-obtrusive observation of people for user behavior analysis (Salah et al. 2013). This context data model will adopt the definition from the World Economic Forum (2011) as follows:

1. Volunteered Data: data that is explicitly provided by the children. This can include personal profile information or preference settings, e.g., the child name and date of birth.
2. Observed Data: data not directly given by the children but is detected by the smart toys often through a sensor, e.g., GPS location and time.
3. Inferred Data: data deduced based on analysis of a combination of volunteered and/or observed data. A lot can be evaluated about a child and their environment through inferences based on context data by third party influencing, e.g., integrate with the information from social networking sites and Google Map.

Cross-References

▶ Children Privacy Protection
▶ Toy Computing

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Social Virtual Reality

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Synonyms

VR Sociable Network

Definition

Social Virtual Reality is a web-based social interaction paradigm, mediated by immersive technologies and taking place in predesigned three-dimensional virtual worlds where individuals, represented by an avatar, may engage in real-time interpersonal conversation and shared activities.

Introduction

Immersive Virtual Reality (VR) evolves for over five decades, whereas the vision of cognitive transcendence to *another reality* could date as far back as the eighteenth century (Grau 2003). The

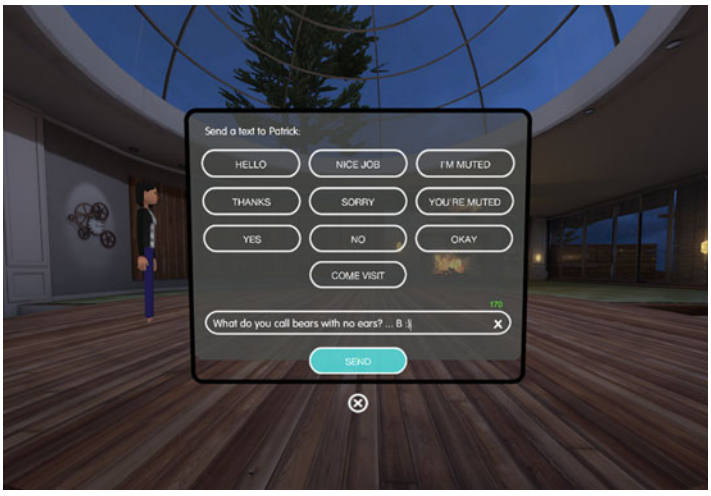
simplest explanation for the much delayed commercial breach of Head Mounted Displays (HMDs) is that the level of immersion is a direct effect of applied illusory techniques (Slater and Wilbur 1997). Therefore, even though original HMD prototypes were developed by Ivan Sutherland in the mid-sixties (Sutherland 1968), being dependent to the autonomous development of contributing technologies – and those are multiple – VR-related progress was slow, but most importantly un-marketable.

Advancements in the overall quality of displays, in combination with the diffusion of Smartphones, enabled the commercial release of affordable VR headsets such as the Google Cardboard and Samsung Gear VR, while HMDs like Oculus Rift and HTC Vive came with built-in displays offering superior content-projection quality. The commercial success was followed by the industry's tapping of an established market, social networks. Thus, social VR refers to the combination of (a) web-based social networking and (b) an egocentric flow of information, a distinctive trait of both immersive VR and users' profile structure in social media. It could be regarded as the *second generation of social networking*, incorporating immersive technologies, which allow users to engage in synchronous, interpersonal interaction with friends or strangers, in predesigned, web-based, three-dimensional (3D) virtual environments (VEs).

Emergence of Social VR

One of the first known attempts in immersive social networking was that of AltSpace (https://altvr.com/), a software company which began developing its homonymous platform in 2013, approximately 2 years before the wide-spread release of HMDs and launched it in May 2015. AltSpace, which has also been the first to embrace the term "social VR," announced closing down due to lack of investors, until its acquisition by Microsoft in October 2017. Starship, a VR/AR (augmented reality) innovation company, launched vTime (https://vtime.net/) in December 2015. Finally, in April 2017, Facebook introduced Facebook Spaces (https://www.facebook.com/spaces) and essentially solidified social VR, since, unlike other platforms, it is structured upon users' existing accounts, uploaded media, and network of friends. Other social VR platforms include Oculus Rooms, VRChat, and Sansar, developed by Linden Lab, the company best known as the creator of Second Life.

Basic functionalities of Social VR platforms entail use of immersive technologies such as HMDs and data-gloves, avatars, and virtual worlds where users can interact among each other in a variety of ways; for instance, AltSpace allows private messaging (see Fig. 1). In addition, some platforms allow users to participate in shared activities like playing games and attending social events. There are also features that could be



Social Virtual Reality, Fig. 1 Private messaging option. (Image courtesy of AltSpaceVR)

Social Virtual Reality, Fig. 2 vTime's *Personal Shield* function. (Image courtesy of vTime)

regarded as a form of Mixed Reality, such as projections of videos, websites, or other media onto virtual screens, visible to all users present. Finally, they feature cross-platform usage and support live videocalls and communication via any application (email, SMS, Facebook Messenger, Skype, etc.) that allows content sharing.

Social VR and Communication

The potential of VR as a communication medium has been foretold over two decades ago (Biocca and Levy 2013) and by all accounts, Social VR is synchronous interpersonal communication. However, it is differentiated from computer-mediated interaction with respect to several aspects.

First, typical social networking is computer-mediated (CMC), text- or image-based, offering both synchronous (by featuring chat and secondary functionalities of video and audio calls) and asynchronous forms of communication. Social VR, although certainly still computer-mediated, would be better described as a simulation of face-to-face (FtF) communication; apart from the use of anthropomorphic 3D models (as the *embodiment* of one's social profile – avatar), the ability for synchronous dialogue (via audio intercommunication), real-time head-tracking, spatialized audio and the incorporation of some germinal nonverbal cues (such as -basic- body posture, e.g., sitting/standing, facing/or not interlocutors, some hand gestures etc.), and proximity between communicators vastly alters the experience of social networking (see Argyle 1988). For instance, both AltSpace and vTime allow the activation of a shield (see Fig. 2), preventing users from virtually touching shielded avatars or invade their personal space.

To this list, we could also add a sense of *being watched*, which is never the case in computer-mediated social networking. Finally, VEs provide an additional aspect to the interaction, since sceneries convey information of *social context* (see Dzardanova et al. 2018) with the probability of affectively impacting communicators' social behavior (see Goffman 1959).

Conclusion

Social VR platforms have not been extensively studied and lack of full body-motion control, haptic feedback, and incorporation of the full spectrum of nonverbal cues possibly affects the overall fidelity. Comparative research and laboratory-based social experiments are in need. Furthermore, VR is a set of continuously evolving technologies, and even though their growth rate is expected to rise significantly in the next few years, it is still unclear whether social VR will hold as a standardized means of social networking.

Cross-References

- ▶ Everyday Virtual Reality
- ▶ History of Virtual Reality
- ▶ Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry
- ▶ Presence and Immersion in Virtual Reality

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Social-, Mobile-, and Multi-Player-Games and Their Impact on Today's Online Entertainment Industry

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Synonyms

Online games; Smart-phone games; Group games Computer games industry; Games industry

Definition

Online games are games that are hosted on a server or that can be accessed by multiple people from different locations. *Social games* rely on the interaction with other (human) players or have strongly interaction-tailored elements. *Multi-player games* are games designed to be played by multiple players at the same time, be it collaboratively or in competition with each other. *Mobile games,* i.e., games that can be played on mobile devices, intersect with all of these three game types.

Introduction

One game, more than any other, has defined a generation in the sense that one is hard pressed to find someone who has *not* played it. That game is *Pac-Man*, invented by Toru Iwatani for Namco Limited in, 1977 (Lammers 2006). The game holds the (Guinness) world record as the *most successful coin operated game ever* (Limited 2008) and is considered by experts such as Levy (2010) to be *the* most famous computer games of all times. For completeness, it should be noted that the 1978 arcade game *Space Invaders* (by Tomohiro Nishikado) is ranked by historical reviews such as Glenday (2009) as the *top arcade game ever*; its arcade version famously causing coin shortages in some countries. *Pac-Man* was created in the earlier years of computer games but it has not lost in appeal at all; for a brief few days it recently resurfaced and shook the world of online gaming: when Google displayed a fully playable version of the game as its logo (maintained for public use at http://www.google.com/pacman/) in May 2010 and made it freely available to anyone on the internet, the world once again played the game excessively. As a result, and over the course of only 3 days, the reported loss in man-hours and productivity across the globe is estimated to greatly exceed $100 million.

These damages seem huge; however, Kushner (2011) already estimated the worldwide gaming community to have grown from 200 million in

2001 to 1 billion by 2011. In 2007 the Entertainment Software Association stated that *"US computer and video game software sales grew six percent in 2006 to $7.4 billion – almost tripling industry software sales since 1996".* By 2008, Bohannon (2008) estimated gaming to be $11 billion industry. These are relatively old numbers, but they plot a decade-long trend. This trend continues until today and does so with staggering numbers: according to Ojala and Tyrvainen (2011), over the last decade the entire software industry (i.e., not just games) has taken the shape of a $200 billion software division and a $500 billion service industry. According to Anderton (2017), the economic impact of the gaming industry (where computer games have long since replaced traditional board and card games in overall profit) to the US GDP in 2016 was $11 billion, with the global industry exceeding $90 billion.

Mobile Devices and their Impact on Computer Games

Two technology driven trends have recently taken the concept of games, and game-play, from being isolated activities and blown them across all spectra of everyday lives of ordinary people: social networks and mobile devices.

Handheld Consoles and Smart Phones as Gaming Devices

Mobile gaming on programmable devices was introduced quite early in the history of gaming, with devices like the *Microvision* (Wolf 2008) or Nintendo's *Game & Watch* (Gorges et al. 2012) being released in 1979 and 1980, respectively. However, the world was not yet ready for *Microvision* and it was produced only until 1981 (Firestone 2006). *Game & Watch* did much better: until it was discontinued in 1991, more than 43 million units were sold and in its 11 years, 60 games were produced for it (Stanton 2015).

The big-break through was clearly the Nintendo *Game Boy* (1989) (Tobin 2013), considered by an entire generation to be *the* handheld unit (Herman 1994). In various incarnations, it sold close to 120 million units in its life time. The *Game Boy* was a major factor for the success of one of the most successful games in history: *Tetris* (Ackerman 2016; Brown 2016). Seeing the success of the *Game Boy,* Sega produced the *Game Gear* (1990) but not nearly with the success of the *Game Boy.* At the end of its life cycle, the *Game Gear* only sold around 11 million units. Nintendo could also follow up to the *Game Boy* with the *Game Boy Advanced* (2001) selling over 80 million units in its considerable shorter life time compared to the *Game Boy* variants. In 2004, as Nintendo released a new handheld console called the *Nintendo DS,* a new competition entered the market of mobile gaming: Sony released their *PlayStation Portable (PSP)*. While the *PSP* was a success selling over 80 million units, its successor the *PlayStation Vita* (2011) failed to deliver: after selling only 15 million units no further follow up device/product was created. With Sony dropping out, Nintendo seems to be the only company being able to succeed in the handheld market, and indeed, the company created commercially successful handhelds in every console generation since the *Game Boy.* Notably, *while the Wii is very often crowned as the winner of the* seventh console generation, continuously selling almost as much as the *XBox360* and *PlayStation 3* combined, the *Nintendo DS* and *3DS* almost sold 50% more than the *Wii*.

The Commercial Success of Mobile Games

In 2005, Chehimi et al. (2005) predicts that *"mobile games will be one of the most commercially successful applications on mobile phones."* They were considered to be a *killer application* and individually attract millions of subscribers worldwide (Aiolli and Palazzi 2009). The revenues they generate are reported to be *"in the order of billions of US dollars worldwide"* (Yan 2003). They are considered to be among the most proliferating industries (Wong et al. 2010) and experience growing demands, with an estimated 40% growth each year: according to Palazzi and Maggiorini (2011), games also represent one of the most successful applications for smart phones.

Even though mobile gaming on smart phones or PDAs was already possible in the early 2000s (Inam et al. 2017) with *Windows Mobile* devices

or devices like the Nokia *NGage,* the success of the iPhone (2007) and the following success of Android (2008) opened a complete new market for mobile gaming. That mobile market is estimated to have grown to $24.5 billion by the end of 2014 (Wang and Che 2016). The most downloaded paid and unpaid apps list are continuously filled with – and often lead by – games. For instance *Candy Crush* has more than 20 million downloads on the Google Playstore alone which can easily compete with AAA games on the consoles such as *Call of Duty.* While fully paid games exist they are a minority on the app stores. Smart phone games quite often rely on the *free2play* model (Soroush et al. 2014), providing a free base game and requiring minor transactions for in-game items. Because of this, *free2play* games are often developed in ways which encourage the user to buy additional in game items.

The continuously increasing processing power of smart phones allows them to compete with hand-held devices and even with some home consoles. However, the lack of standardized gaming inputs on smart phones (other than the touch screen) limits the types of games that can be realized on them. This difference in input methods and therefore different games results in different demographics for the different platforms (cf. Amaro et al. 2016).

Social Networks and their Impact on Computer Games

According to Kushner (2011), (at least) with regard to North Americans, Nielsen Co. puts social networks and social games as the top two reported internet activities. The number of users of social games, such as *Car Town* (with eight million users), *Hero World* (with seven million users), or *Mafia Wars* (with 16 million users), cf. Laplante (2011), shows that social games motivate large numbers of humans to engage in collective online social activities.

Social Network Based Games

According to Kushner (2011), the game *Farmville* reported numbers as staggeringly high as 50 million users per month. *Candy Crush,* considered by, e.g., Amaro et al. (2016), to have been the most popular social game for a while, reported at times close to 11 million daily active users on Facebook. These games and their wide-spread play have finally changed the image of computer games in the public's opinion. This is unsurprising, considering that according to the reported numbers, at least one out of six people alive today is occasionally playing computer games in one way or another. The biggest hits seem to be so-called *social* games, games which are not only involving some social aspect but are also based on social web sites. This, combined with the fact that modern computers are found in almost every household in the first world, is probably the driving factor responsible for the mentioned explosion in user numbers.

The proliferation of computing power through everyday households is not new: already in 2003 David Anderson, the founder of the Berkeley Open Infrastructure for Network Computing (BOINC), declared that the majority of the world's computing power is now found in the millions of personal computers distributed all over the world (Rinaldi 2009). The applications that make use of this idle power and, more importantly, the assistance of humans interacting with the applications are shown to range from the search for extra-terrestrial life (*SETI@home*) over research for cures for cancer (Help Defeat Cancer, *HDC*) and AIDS *(FightAIDS@home*) to protein folding. Especially the game *Foldit,* originally designed to use the idle time of private computers to predict protein structures while providing the output of the progress as a screen saver has received large attention in the academic press (cf. Cooper et al. 2010; Khatib et al. 2011; Hand 2010). The application evolved into a game, where the computational effort is greatly assisted by human players insight and capabilities.

Multi-Player Network Games

Multi-player network games have existed for more than 30 years (Hasan 2010) and constitute a seizable part of today's (mobile) gaming landscape. Games like *EverQuest* earn/earned Sony an estimated $5 million per month from subscriptions alone, and this is certainly not the only

major game available: as Yan (2003) reports, online games such as *Ultima Online, Diablo II,* and Korea's *Lineage* have also achieved huge commercial success.

While engaging in games online and with others was already possible in the 1980s, the rise of the internet in the 1990s allowed for a major development in the gaming world. During the 1990s, the evolution of games went along with the internet and developed many systems which are still present and defined how online multi-player is today. While early games like *Doom* (1993) required the player to exchange IP addresses to play together, more and more comfortable ways were introduced to allow players to join together. With the widespread use of dedicated servers games like *Quake* (1996) introduced address lists which allowed the player to manage the servers. But the problem of requirement to know the IPs remained. This led to the development of server browsers like *QSpy* (later *GameSpy*) which operated as listing servers. Blizzard's *battle.net* service was first introduced in 1996 with the game *Diablo.* It provided – next to an integrated server browser – also a pre-game lobby system allowing players to team up before joining a game. Voice over IP (VoIP) services like *battlecom* or *Roger Wilco* allowed players to communicate more direct during the games.

Online Gaming Platforms

With the turn of the century the online multi-player concept made its way from PCs to consoles. Even though online services for consoles were already available from the 1980s on, starting with Ataris *GameLine* (1982) followed up by services from other companies like Sega with *SegaNet* (1994), they were only used to distribute games. One of the first online multi-player implementations for consoles was the *X-Band Modem* (1995). X-Band only supported a limited number of games on the *Super Nintendo Entertainment System* and the Sega *Genesis.* Ultimately the X-Band Modem was not successful and the company eventually folded in April 1997.

The first console to support online connectivity from the start was the Sega *Dreamcast* having a 56Kbps modem. Sega was ultimately failing and ended the production of the *Dreamcast* and thus of the *SegaNet.*

While the *Playstation 2* and the *GameCube* were provided with various types of network adapters, not making online multiplayer a core part of the systems, Microsoft launched the *XBox* with an included RJ45 network connector and, shortly thereafter, the *XBox Live* service. This service provided console players with various features like VoIP or friend lists next to the online multi-player which should become standard for online gaming services. With the success of the *XBox Live* service, the next generation of consoles saw a complete integration of online services, spawning the *PlayStation Network* as well as *Miiverse* (Nintendo).

Massively Multi-Player Games and eSports

The continuous spread of broadband internet connections and better infrastructure allowed also for bigger online games. While *World of Warcraft* is definitely not the first Massively Multi-player Online Role Playing Game (MMORPG), with (at its peak) 12 million users it is one of the biggest ones.

Better internet connections also brought the rise of the *eSports* scene. This more competitive aspect of online gaming saw the rise of a new genre: the *Mobile Online Battle Arena* games. Games such as *Dota 2* or *League of Legends* have prize pools reaching up to $24 million.

The Impact on the Gaming Industry

Security Requirements

The sheer order of magnitude and the nature of the distributed character of platforms have fundamentally changed security requirements for computer games. Yan (2003) argues that security, along with graphics and artificial intelligence, is emerging as an inherent design issue for online games; the dominant approach to copyright protection (which changed from protecting the information about the workings of the console to protecting the actual games) has been partly abolished again and is experiencing a reversal in some sense: the games depend less and less on the code that runs

the game and increasingly on the platform on which to run it (i.e., the ability to play against/with others). It should be noted that not all big multi-player online games are basing their business model on subscriptions though: for example, the online resource management game *Ogame* (Koutero et al. 2010) is free to play for anyone with internet access and (maybe because of this) has a large following of dedicated users which contribute to and maintain an extensive forum.

Monetization

The rise of popularity of online gaming can also be seen in numbers. A top seller of the online first person shooter genre *Call of Duty Modern Warfare 2* reported a starting day income of $310 million while the top income for the opening day of a blockbuster movie in cinema is *only* $119 million.

The latest big change in online gaming was not a technical change or a new feature but a change in the monetization of games. The introduction of micro-transactions allowed publishers to get a continuous stream of income during the life time of a game. Many features which used to be free or unlockable by game-play, like different skins or new characters, are sold for small amounts of real money. This business model let to a lot of controversies like the "*on disc"* DLC (downloadable content) from *Street Fighter X Tekken,* where extra characters, available for purchase separately, were already supplied on the originally purchased disc. Publishers and developers regularly claim that micro-transactions and DLC are needed to support further development and support for games. However, as in the case of *Street Fighter X Tekken,* many of their customers feel that this is inherently untrue since the content was already produced and the full code included in the original purchase (albeit not available in the game).

Advertisement

While from the 1990s and to the 2000s and 2010s almost every major announcement in the gaming world happened at trade shows like the *E3*, the rise of video streaming shifted this more and more to the social media platforms. This allowed the publishers to address their customers directly instead of only through the press. Even end customer trade shows like the *GamesCom* (350,000 visitors in 2017) do not even closely address the amount of people of a youtube video like the *Battlefield 1* trailer (having over 50 million views). Nintendo remarkably completely stopped attending the *E3* from 2013 onward and releases their own presentation video aside the trade shows.

With the rise of the popularity of the *Let's Play* genre game developers and publishers saw this as a new way to advertise their games. Companies like EA Games or Activision have dedicated events where *YouTubers* get invited to play their games and record videos. Remarkably, in 2017 Jason Blundell, Co-Studio Head of Treyarch (*Call of Duty*) made the decision to announce a big add in the bedroom of a *YouTuber* instead of at a trade show or through a special event, as it was standard in the industry until then.

While some companies see social media and especially *Let's Play* videos as free advertisement for them and rather rarely request a video take down, others like Nintendo have programs which allow them to participate in the monetization while exercising higher control over what is broadcasted.

Social media did not only allow the publishers to address their customers more directly but also the other way around. From expressing aesthetic dislikes (e.g., in the case of the (*Call of Duty Warfare*) trailer which as of December 2017 has over 3 million dislikes over technical feedback and game mechanic changes to even changing the aspects in the monetization (such as the removal of the money auction house for (*Diabolo 3*) or the 2017 (*Battlefront 2*) controversy) gamers are using all of the existing social media platforms to tell the developer what they like and what they don't like.

Conclusion

In the last decade, and due to the pervasive nature of mobile devices, there has been increased interest in the use of this technology for all types of applications, including computation intensive optimization programs (e.g., Branki et al. 2008; Bitterberg

et al. 2009, 2011). This indicates that the average handheld device is computationally capable to serve as a platform for educational (Hildmann and Hildmann 2012a, b) games, for games-based evaluation and assessment tools (Hildmann and Boyle 2009; Hildmann 2013), or for the gamification of behavioural interventions (Bitterberg et al. 2008; Hildmann and Hirsch 2008; Al Houqani et al. 2013; Hildmann et al. 2009).

Cross-References

- Computer Games and Artificial Intelligence
- Computer Games in Education
- Gamification
- Gamification and Serious Games
- Machine Learning for Computer Games
- Origin of Games
- Serious Online Games for Engaged Learning Through Flow

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Sociality of Digital Games

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Synonyms

Multiplayer games; Social games

Definition

The sociality of digital games encompasses a diverse range of interactions involving both players and their in-game representations. These interactions may have both positive and negative effects on players' real-life social relationships. They can also enable identity play and self-expression, as well as develop empathy in players.

Introduction

There exists a perception in the popular imaginary that digital games negatively affect players' social skills (Kowert and Oldmeadow 2014). Existing research, however, has not reached a consensus on the matter. While some researchers have found that playing even multiplayer games can be a solitary and isolated experience (Ducheneaut et al. 2006), others have reached the opposite conclusion, discovering, for example, that playing massively multiplayer online games (MMOs) can increase older adults' social interaction (Zhang and Kaufman 2015), or that some games can

promote empathy and decrease schadenfreude in players (Greitemeyer et al. 2010).

Importantly, the framing of this discussion is based on a restrictive, normative view of sociality as something based on people's face-to-face interactions. Such a view does not account for the complexity of manifestations of sociality in and around digital games. This entry outlines some of these manifestations.

Interpersonal Sociality in Games

Games as Environments/Media

Multiplayer games create environments where avatars controlled by players interact. As avatars do not need to correlate with players' real-life identities in terms of gender, race, faith, and even species, this opens up rich possibilities for self-expression. MMOs thus often become spaces of identity play, allowing players to "express themselves in ways they may not feel comfortable doing in real life" (Cole and Griffiths 2007) by constructing an avatar different from their physical selves in appearance, gender, and age, as well as behavior. Identity play is also often richly social, leading to avatar conversations, friendship, and even marriage (including same-sex marriage between avatars controlled by players from countries where actual same-sex marriage is legally problematic, such as China; see Li et al. 2008).

Multiplayer environments can, however, produce very different kinds of sociality. Some in-game virtual communities emerge spontaneously for the purpose of a single match or tournament only, as in the case of the Swedish *Armed Forces' Team Test* (2010), where four anonymous participants are formed into a team which then has to face numerous challenges that require teamwork to complete. Virtual communities can also be recurrent if players return to the same, if constantly evolving, world every time they enter the game, as in *World of Warcraft*.

In-game interactions between avatars are not isolated from players' real lives. According to Cole and Griffiths (2007: 582), 39.3% of online gamers reported discussing "sensitive issues with their online gaming friends that they would not discuss with their real life friends," 42.8% "had met with online friends in real-life situations," and 10.1% "had developed a physical relationship with another player," substantiating the idea that the dichotomy between real-life and virtual sociality is a false one (Lehdonvirta 2010). This is further evident when considering the example of *CitiTag* (2004), a mixed reality mobile game which tracks its players' geographical location and spontaneously assigns people into competing teams based on the whereabouts of their physical selves in order to facilitate social interaction. Professional esports supports the same point from a different angle, as it enables real-life inter- and intrateam interaction (Freeman and Wohn 2017), as well as spectator play.

On the other hand, as Ahlstrom et al. (2012) point out, excessively playing MMOs can harm one's existing real-life relationships, for example, negatively affect marital satisfaction, leading some spouses of MMO players to identify as "gamer widows" (Lianekhammy and Van De Venne 2015). MMO communities are also known to struggle with cyberbullying and toxic behavior, despite having provisions for reporting and penalizing it, which are often underutilized (Kwak et al. 2015). One notable problem is sexism. In Brehm's (Brehm 2013) study, for example, 63.6% of female *World of Warcraft* players reported experiencing sexist behavior in the game. The hierarchical structure of many multiplayer games can also lead to cronyism and power abuse (Meachem 2012).

Games as Environments/Media

A different social dynamic is when interpersonal interaction arises *around* a digital game, not inside it. One manifestation is player activity on forums and social media, where strategies, experiences, and ideas are shared, often using a separate nickname from their in-game avatar or (on social media) disclosing their real name. These groups of players can be seen as "communities of interest," as they "bring together participants who interact extensively about specific topics of interest" (Armstrong and Hagel 2000: 85) without

necessarily getting to know each other outside these topics. In many game-related online communities, collaborative content production also actively takes place, making them "communities of practice" (Wenger 1998). Modding communities, which revolve around modifying or creating alternative versions of a digital game (Sotamaa 2010), are a prominent example.

Playing digital games together with one's friends or family is another type of activity whose essence lies not in the content of the game itself but in the social interactions around it, as well as the shared experience which play produces (Cole and Griffiths 2007; DiSalvo and Bruckman 2010). Often, such settings lead to "vicarious play," whereupon some of the players participate in the play mentally and verbally, without actually using game controls (De Schutter and Vanden Abeele 2010). The increasingly popular "Let's Play" videos on platforms such as YouTube often seek to replicate this feeling of playing together, though with an emphasized performative dimension (Glas 2015).

Parasocial Interactions in Games

Like any art form, digital games often seek to elicit an emotional response from the player by getting them involved in parasocial relationships, i.e., "relationship[s] between media users and media figures (from celebrities to fictional characters)" (Giles 2002). Mourning the death of a hero, resenting the antagonist, or suffering from a "breakup" with the protagonist after completing a game series are all forms of parasocial relationships. However, what is more specific to the medium of digital games is that characters can react to the player's input and "talk back," enabling "paracommunication" (Hartmann 2008) between the player and the character. Coulson et al. (2012) have concluded that "people form real and authentic emotional attachments to virtual characters," suggesting that parasociality may not be experientially different from regular sociality. Greitemeyer et al. (2010) provide further evidence of that by demonstrating that playing "prosocial games" can increase players' empathy.

Conclusion

Sociality within and around digital games has a diverse range of manifestations, which challenges the simplistic, yet still common, discourses of games being anti- or asocial. However, in order to understand the complexity of the social effects of digital games, a broader view of sociality needs to be adopted than the prescriptive notion of sociality as being based on face-to-face interactions between people.

Cross-References

▶ Player-Avatar Link: Interdisciplinary Embodiment Perspectives

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Software

▶ Virtual Reality Game Engines
▶ Virtual Reality Stereo Post-Conversion After Effects Workflow

Software System

▶ Unified Modeling Language (UML) for Sight Loss

Software Testing

▶ Quality Assurance-Artificial Intelligence

SOG: Serious Online Game(s)

▶ Serious Online Games for Engaged Learning Through Flow

Solid-Free Form Technology

▶ 3D Printing, History of
▶ Open Source 3D Printing, History of

Sonic Adventure 2, an Analysis

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Synonyms

Platformer

Definitions

Platformer A game genre where a character must maneuver through obstacles by jumping, climbing, etc. to reach a goal.

Sonic Adventure 2 - A Platform Game

Sonic Adventure 2 is a platformer that was developed by Sonic Team and published by Sega as an anniversary title in the Sonic the Hedgehog series. It has been released three times on five different consoles: the original release on the Sega Dreamcast on June 20, 2001, Sonic Adventure 2: Battle, a remake of the original with updated lighting and additional content released on Nintendo Gamecube on February 11, 2002, and Sonic Adventure 2 HD, which was released on PlayStation 3 and Xbox 360 on October 2, 2012, and PC on November 19, 2012. It is primarily single player with a story mode featuring three stories, a level select to replay levels for better times or to get more collectibles, and several other minigames. There is also a multiplayer mode where you can race through edited levels. It was given a rating of E10+, higher than Sonic Adventure, due to the mention of some characters dying and an overall darker plot (Entertainment Software Rating Board).

The game's target audience was primarily teenagers and up, as shown by the darker and more complicated story compared to previous games in the series. It is the followup to 1998's Sonic Adventure, continuing and enhancing the newfound 3D style. It was created to celebrate the 10th anniversary of the franchise and introduces two new major recurring characters to the series, Rouge the Bat and Shadow the Hedgehog. The story is split up into two main stories – Hero and Dark – and one unlockable story that ties it all together, the Last story. It involves the series protagonist, Dr. Eggman, unsealing Shadow from stasis to get his assistance in taking over the world. Sonic, mistaken for Shadow by the police, gets wrongly apprehended but manages to escape with help from his friends, Tails and Knuckles. They then figure out Eggman's plans and work together to end his plan. Major characters include Sonic, Tails, a fox who is Sonic's best friend and sidekick, Knuckles, an echidna who guards a powerful gem called the Master Emerald. These three make up the Hero team. The Dark team includes Shadow, an artificial life form known as the Ultimate Lifeform, Dr. Eggman, an evil genius who wishes to control the world using robots and his own intelligence, and Rouge the Bat, a treasure hunter hired as a government spy to covertly work with Eggman to uncover more information about Shadow. Other minor characters include Amy Rose, a pink hedgehog who follows Sonic everywhere he goes, and the President, who rules over the United Federation and attempts to negotiate with Eggman.

The game includes 32 stages, divided up by the six characters. Sonic has seven stages, with one being unlockable by getting all collectibles, Tails has five stages, with one being a kart driving stage, Knuckles has five stages, Shadow has four stages, Eggman has five stages, and Rouge has five stages, one being a kart stage. There is also one last stage, Cannon's Core, which serves as the final level in the whole game where you switch between all characters except for Shadow. There are also boss and rival stages where each character will fight a large enemy or their counterpart from the other team.

The game has three different play styles with two characters assigned to each style. The first are the running stages, where the goal is to get to the end of the stage, either defeating or ignoring enemies along the way. These stages are played as either Sonic or Shadow. The next are shooting stages, where the characters get into a mech walker with the goal of destroying as many enemies as possible then make it to the end of the stage. They are much slower, with more emphasis on defeating enemies than going fast. These are played as either Tails or Eggman. The final style are treasure hunting stages, where the goal is to find three of a specific object, typically being Master Emerald shards, but can also be keys or other gems. These are played as either Knuckles or Rouge.

The public opinion of the game varies wildly, like many of the other 3D Sonic games. On one

hand, many people call it the best example of 3D Sonic gameplay, having one of the more memorable stories in the series and introducing a strong character in Shadow. Others speak more negatively of the game, citing a particularly bad camera in some sections, gameplay other than the running stages being either frustrating or not fun at all, and the unequal division of stages; one of the most important characters, Shadow, only got four stages. There are a few major plotholes that people cite as proof that the story is not very good. For example, the premise of one of Rouge's levels is completely pointless and avoidable (Metacritic). Eggman orders her to break into a government vault in order to steal three gems to proceed with their plan. However, being a double agent, there is no reason she would have had to break in, when she could have just requested the emeralds and make it look like she broke in. Another point of contention is the controls. Actions, such as shooting, picking up objects, somersaulting, and other maneuvers are all mapped to one button, with the longer you hold it down determining the action you take. This can become very clumsy, leading you to roll off a ledge when you are trying to interact with another object, wasting precious time and potentially costing you a life. There are several fixes for this, all involving using one of the several other buttons available.

Overall Sonic Adventure 2 is a game that has a few flaws, but has stood the test of time and holds a place in the hearts of fans for being a solid platformer.

Cross-References

► Video Games

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Entertainment Software Rating Board. https://sonic.fandom.com/wiki/Entertainment_Software_Rating_Board

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Sonic Interactions in Virtual Environments

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Synonyms

Audio design; Sound and music computing; Sound synthesis

Definitions

Sonic interaction design is defined as the study and exploitation of sound as one of the principal channels conveying information, meaning, and aesthetic/emotional qualities in interactive contexts. This field lies at the intersection of interaction design and sound and music computing.

Introduction

In recent years, the availability of low-cost head-mounted displays has enhanced the interest toward immersive sound experiences. Investigations on 3D sound in the context of virtual reality (VR) are not a novel topic (Begault and Trejo 2000). In an interactive immersive experience, sound can direct the attention of the user and enhance the sense of presence (Hendrix and Barfield 1996; Nordahl and Nilsson 2014; Serafin and Serafin 2004) and the ability to move users by creating interactive time-varying experiences (Nordahl 2006). The auditory modality possesses unique features. Unlike its visual counterpart, auditory perception is always turned on, since one cannot close the ears. Thus, this sensory channel always flows with information about the surrounding environment, regardless of whether one is attentive to this information or not (Gilkey and Weisenberger 1995). Visual perception is superior in terms of spatial resolution, but it is

inherently directional. Our limited field of view entails that one has to turn the head or body in order to perceive the surrounding environment. Auditory perception, on the other hand, is omnidirectional (Pope and Chalmers 1999). Moreover, as highlighted, for example, by Larsson and his colleagues (Larsson et al. 2010), auditory cues are inherently temporal in nature. A sounding event is by definition an unfolding event. In sum, it appears that auditory displays constitute a relatively inexpensive and valuable component of VR systems intended to represent multimodal virtual spaces and elicit a sensation of presence in these spaces. In the past decades, several methods have been developed for the automatic generation of sound by making use of techniques developed in computer graphics, such as texture mapping/synthesis (Takala and Hahn 1992) and rigid body simulations (Van Den Doel et al. 2001). These methods make it possible to create realistic sound related to objects in motion and depending on the geometric relationship between the receiver and the sound source. Sound synthesis and rendering are slowly becoming an important research field even in virtual reality.

Several research questions, however, remain open, especially when 3D sound is embedded into ecologically valid interactive multisensory experiences. In these situations, results from investigations of the role of 3D sound in static unisensory experiences might not still hold as valid.

In this article an overview of the state of the art of immersive sound rendering is provided. Although immersive sound can be delivered through a speaker setup or headphones setup, here the focus is on sound rendering through headphones, since it is the hardware solution available with state-of-the-art consumer head-mounted displays. Headphone-based sound rendering makes it possible to completely control the sound arriving at each ear. In addition to offering more precise control of binaural cues, unwanted sounds such as echoes and reverberation are kept from reaching the ears of the listener. However, this comes at a price since the headphones may be experienced as intrusive by the user (Shinn-Cunningham and Shilling 2002).

Immersive Sound for Virtual Reality

A complete immersive sonic simulation needs to take into account action sounds, environmental sounds, sound propagation, and binaural rendering. Action sounds are those sounds produced by the user which need to change according to movements. One of the essential elements of sound events in VR that distinguishes them from film is the importance of interactivity: actions of the users such as walking, hitting, throwing, etc., often generate sounds. Ballas (2007) refers to such action-based sounds as self-sounds and describes them as sounds that are produced by one's own body or body movements, which need to vary according to the action of the user. Environmental sounds are those sounds produced by objects in the environment, as well as the soundscape of the space. Sound propagation represents the simulation of the acoustics of the space, either a closed space such as a room or an open space. Binaural rendering relates to how the sound reaches each of our ears and allows us to perceive sounding objects as placed at a specific azimuth (horizontal direction), distance, and elevation. In the literature the term, virtual acoustics has been used to cover the three main elements of the system: source modelling, room acoustics modelling, and receiver modelling (Savioja et al. 1999). One of the first complete virtual acoustics systems that includes all three elements is the system developed at Helsinki University of Technology (Huopaniemi et al. 1996). In a traditional audio design pipeline, a monophonic sound is synthesized, and then it is spatialized, e.g., virtually positioned in its environment.

Simulating sound events for VR imposes additional challenges as opposed to sound events for film or other interactive media such as games. One essential difference between immersive and non-immersive interactive media is the fact that users are fully surrounded by the environment. In these situations sound can help to direct the attention of the user or enhance the sensation of place and space. In this article all the elements that produce an immersive sonic experience are examined.

Action Sounds

For action sounds and environmental sounds, here the focus is on sound synthesis algorithms that have been used in real-time contexts, for their relevance in virtual reality simulations. While the computer music community has a long tradition of using real-time sound synthesis, specifically for the simulation of musical instruments (see, e.g., (Morrison and Adrien 1993; Smith 1992; Välimäki and Takala 1996; Cook 2002)), this is not the case for virtual reality.

One of the first examples of the use of physics-based models for interactive audiovisual environment is the work presented in Van Den Doel et al. (2001). Here the authors present a simulation of different solid interactions such as impact, friction, rolling, and using a combination of physics-based simulations and recordings extracted from real objects. The authors use a synthesis technique known as modal synthesis (Adrien 1991). The main principle behind modal synthesis is the decomposition of vibrating objects in their modes, e.g., the resonances of the system. Each mode can be simulated as a mass-spring system or an exponentially decaying sinewave.

In O'Brien et al. (2002), a real-time technique for generating realistic and compelling sounds that correspond to the motions of rigid objects is presented. In this case the actions are not necessarily actions of the user in the environment but actions between objects present in the simulation. By numerically precomputing the shape and frequencies of an object's deformation modes, audio can be synthesized interactively directly from the force data generated by a standard rigid body simulation. This approach allows to accurately model the sounds generated by arbitrarily shaped objects based only on a geometric description of the objects and a handful of material parameters.

In Avanzini et al. (2005), the authors presented some efficient yet accurate algorithms to simulate frictional interactions between rubbed dry surfaces. The work is based on the assumption that similar frictional interactions appear in several events such as a door squeaking or a rubbed wineglass. For this reason, the same simulation algorithm can be used with different parameters adapted to the different objects interacting. In Avanzini and Crosato (2006), an algorithm similar to the one presented in Avanzini et al. (2005) is adapted to simulating impacts in multimodal applications.

Environmental Sounds

The class of environmental sounds covers a large variety of sounds since it relates to all events occurring in the listener's surroundings. Consequently, a generic definition of such sounds cannot be easily found (Verron et al. 2010).

One of the first researchers interested in investigating environmental sounds from a simulation perspective was Gaver (1993). He proposed a taxonomy of environmental sounds supported by the physics of sound events.

Sound Propagation

Sound propagation refers to the simulation from the sound-producing object to the ears of the listener. A complete survey of methods for sound propagation in interactive virtual environments is described in Funkhouser et al. (2003). A primary challenge in acoustic modelling of sound propagation is the computation of reverberation paths from a sound source to a listener (receiver) (Kleiner et al. 1993). As sound may travel from source to receiver via a multitude of reflection, transmission, and diffraction paths, accurate simulation is extremely computationally intensive.

One simple approach to simulate the space is by capturing the so-called impulse response and convolving it with the original dry signal (Begault and Trejo 2000). This method is simple but lacks flexibility. Therefore several geometric, wave-based, and hybrid methods have been proposed for sound propagation modelling. Wave-based techniques can be mathematically and computationally expensive, so alternative efficient solutions need to be investigated in order to use these techniques in real-time simulations. In James et al. (2006), preprocessing of analogous

global sound radiation effects is investigated for a single vibrating object, showing that expensive linear acoustic transfer phenomena can be largely precomputed to support efficient real-time sound synthesis.

An efficient and accurate sound propagation algorithm is also proposed in Raghuvanshi et al. (2009). The proposed technique relies on an adaptive rectangular decomposition of 3D scenes to enable efficient and accurate simulation of sound propagation in complex virtual environments. In Savioja (2010) a wave-based simulation is proposed, which combines finite difference methods together with computation on the GPU. In Mehra et al. (2014), an efficient technique based on precomputing a set of pressure fields due to elementary spherical harmonic (SH) sources using a frequency domain wave-based sound propagation technique is proposed. An extension of the technique is proposed in Mehra et al. (2015), where an interactive wave-based sound propagation system for efficiently generating accurate and realistic sound is proposed. The approach is based on a recent numerical solver for the acoustic wave equation called the equivalent source method (Mehra et al. 2013).

In Mehra and Manocha (2014), a set of efficient wave-based propagation techniques for VR applications that can handle large scenes and directional sound sources and generate spatial sound are presented. The proposed techniques have been used to demonstrate realistic acoustic effects, such as diffraction, high-order reflection, interference, directivity, and spatialization, in complex scenarios.

Geometric techniques such as the one proposed in Funkhouser et al. (1998) use precomputed spatial subdivision and beam tree data structures to enable real-time acoustic modelling and auralization in interactive virtual environments. Hybrid solutions combining wave-based and geometric techniques have been proposed in Yeh et al. (2013). Here numerical wave-based techniques are used to precompute the pressure field in the near-object regions and geometric propagation techniques in the far-field regions to model sound propagation.

Efficient simulations of reverberation in outdoor environments are a field with limited research results. Recently, however, an efficient algorithm to simulate reverberation outdoor based on a digital wave guide web is proposed (Stevens et al. 2017). The design of the algorithm is based on a set of digital wave guides (Smith 1992) connected by scattering junctions at nodes that represent the reflection points of the environment under study. The structure of the proposed reverberator allows for accurate reproduction of reflections between discrete reflection points. This algorithm extends the scattering delay network (De Sena et al. 2011) proposed for reverberation in computer games.

Binaural Rendering

Binaural hearing refers to the ability of humans to interpret sounds arriving at both ears into complex auditory scenes.

Shinn-Cunningham and Shilling (2002) distinguish between three types of headphone simulation, namely, diotic displays, dichotic displays, and spatialized audio. The first simply refers to the display of identical signals in both channels, something which gives the listener the sensation that all sound sources are located inside the head (Shinn-Cunningham and Shilling 2002). Secondly Shinn-Cunningham and Shilling (2002) refer to stereo signals that just contain frequency-dependent interaural intensity or time differences as dichotic displays. The two authors describe this type of display as very simply since the effect can be achieved by scaling and delaying the signal arriving at each ear. Just as diotic displays, this does not enable proper spatialization of the sound sources since listeners may get the feeling that the sounds are moving inside the head from one ear to the other (Shinn-Cunningham and Shilling 2002). Finally, spatialized sound makes it possible to render most of the spatial cues available in the real world. This is made possible by the use of various cues, such as provided by the head-related transfer function (HRTF), sound reflections in the

surrounding space, or dynamic modifications of these cues caused by head movements (Kendall 1995). Several current research efforts are examining the development of HRTF personalization for individual users of a virtual audio display.

In Meshram et al. (2014), a technique to obtain personalized HRTFs using a camera is proposed. The technique combines a state-of-the-art image-based 3D modelling technique with an efficient numerical simulation pipeline based on the adaptive rectangular decomposition technique (Raghuvanshi et al. 2009). In Geronazzo et al. (2016), the SelfEar project is presented, aimed at low-cost acquisition and personalization of HRTFs on mobile devices.

An important component of the modelling of sound propagation for VR is the spatialization of the room impulse response (RIR) for directional listeners. This involves convolution of the listener' s head-related transfer function (HRTF) with the RIR to generate a spatial room impulse response (SRIR) which can be used to auralize the sound entering the listener's ear canals. Previous approaches tend to evaluate the HRTF for each sound propagation path, though this is too slow for interactive VR latency requirements.

In Schissler et al. (2017), a new technique is presented for computation of the SRIR that performs the convolution with the HRTF in the spherical harmonic (SH) domain for RIR partitions of a fixed length.

Applications

All the examples considered until now have focused on the technological side of immersive audio, from creating sound events, to binaural sound, and sound rendering in space. In the following the focus is on the content and design of different recently developed immersive experiences where sound plays a fundamental role.

In Summers and Jesse (2017) and Summers et al. (2015), the authors discuss specific immersive and aesthetic auditory design techniques as applied to create full-motion, multi-participant virtual reality game experiences for live commercial location-based entertainment (LBE) installations. The authors introduce fundamental design considerations and emerging best practices used in spatially responsive virtual reality audio design and implementation and complement these with practical examples that embrace the complexities of immersive and aesthetic audio design in virtual reality. The design considerations are based on the understanding that audio has the potential to craft the story elements of a product, control the pacing of an experience, enforce the narrative, elicit and influence emotion, create mood, shape perception, and reinforce the way people experience characters.

In Janer et al. (2016), audio signal processing and VR content are combined to create novel immersive experiences for orchestral music audiences. In VR, the auralization of sound sources of recorded live content remains still a rather unexplored topic. In this article a multimodal experience is built, where visual and audio cues bring a sonic augmentation of the real scene. In the particular scenario of orchestral music content, the goal is to acoustically zoom on a particular instrument when the VR user stares at it. The ultimate goal is to improve the learning aspects of music listening, either for education or for personal enrichment.

Virtual reality musical instruments are also a field where naturally physics-based sound modelling and rendering play an important role. For a recent overview of virtual reality musical instruments, the work presented in Serafin et al. (2016) is a good reference.

Carefully designed sounds can be used to reproduce the acoustics of specific spaces, such as the Notre-Dame Cathedral (Katz et al. 2017). In this particular situation, a computational acoustic model of the acoustics of the space was captured and reproduced to be utilized in an immersive VR experience.

Finally, assisted listening and navigation for partially or fully visually impaired users are an example of an important application of interactive sound rendering for virtual environments. As an example (Valimaki et al. 2015), an overview of the use of augmented audition for navigation is presented.

Conclusion

In this article the author presented an overview of the state of the art of interactive sound rendering from immersive environments. As shown in this paper, in recent years several progresses have been obtained in the three different elements of the sound design pipeline, e.g., source modelling, room acoustics modelling, and receiver modelling. From the point of view of source modelling, many sound events have been synthesized, and real-time simulations exist. However, these simulations have not yet been adopted in commercial software engines usually adopted in the VR community. These can be due to the fact that the quality of the simulations is not high enough, so professionals still prefer to rely to recordings, despite their limitations such as the fact that they do not show the same flexibility as simulations.

Room acoustics modelling has also shown several progresses, and efficient algorithms combined with increase computational power make such models available in real time. Further research is needed to adapt these models to several environments, from outdoor to indoor, and to better simulate the acoustic sensation of moving in different spaces such as a tunnel, an arch, etc.

Finally, an active field of research is the capturing and implementation of personalized HRTFs. While listening tests in static environments have shown that subjects have a better sensation of space with personalized HRTFs, it is not yet investigated whether high-fidelity personalized HRTFs are needed in complex virtual environments where several independent variables are present such as the visual elements of the environments and the action of the user.

Cross-References

- ▶ Immersive Auralization Using Headphones
- ▶ Sound Spatialization
- ▶ User Acoustics with Head-Related Transfer Functions

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Soulslike

▶ Dark Souls RPG Through the Lens of Challenge

Sound and Music Computing

▶ Sonic Interactions in Virtual Environments

Sound Design

▶ Spatial Audio and Sound Design in the Context of Games and Multimedia

Sound Novel

▶ Visual Novel

Sound Spatialization

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Synonyms

Auralization; Binuaral headphone reproduction; Loud-speaker reproduction; Room acoustics; Room response equalization; Spatial room acoustic; Spatial room impulse response; Virtual acoustics

Definitions

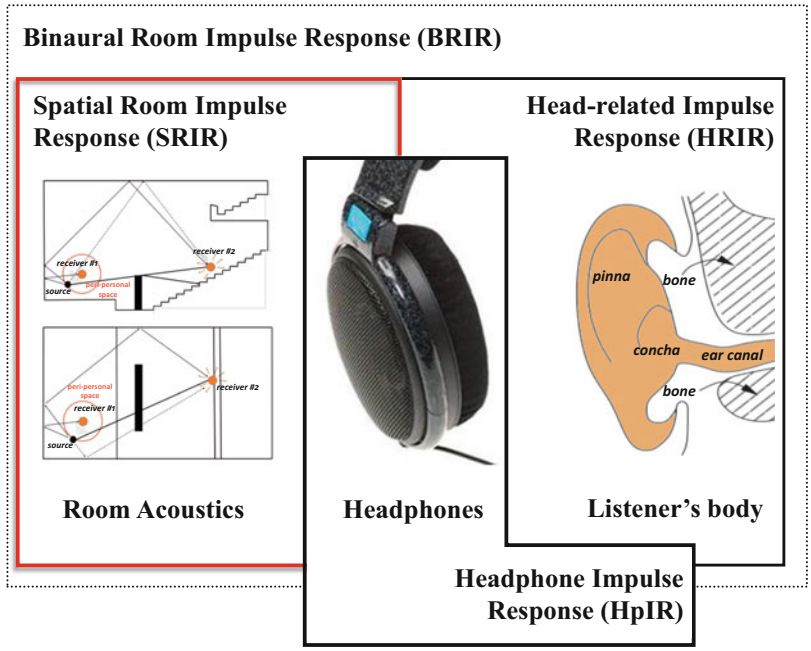
The general term sound spatialization refers to a reproduction system and their algorithms that combined together provide a real-time and interactive rendering or auralizaion for an immersive sonic experience in virtual reality scenarios. Four main aspects can be considered: (i) physics-based simulation of sound sources, (ii) their propagation in space together with (iii) binaural rendering to simulate user acoustics in the listening space or sound-field en-coding/decoding for multiple loudspeaker reproduction, and finally (iv) the technological mediation for listening through headphones/loudspeakers and for interaction trough motion capture. Finding the trade-off between accuracy and perceptual plausibility is the key aspect while considering always evolving hardware solutions for such complex simulations.

Introduction

A high fidelity but efficient sound simulation is an essential element in immersive virtual reality (VR). Continuous advances in hardware and software technologies fosters interaction between virtual sounds and humans in rendering experiences with increasing level of realism and presence.

From the literature, one can refer to the general term auralization that covers the three main components for sound spatialization (Savioja et al. 1999): source modeling, room acoustics modeling, and receiver modeling. A schematic view of those aspects can be seen in Fig. 1.

It has to be noted that many algorithms for virtual acoustics are computer vision and graphics rendering techniques (see entry "▶ Computer Vision") that are adapted to take into account for sound generation and propagation. Some examples are texture mapping/synthesis (Takala and Hahn 1992), beam tracing (Funkhouser et al. 1998), and rigid body simulations Van Den Doel et al. (2001), allowing the synthesis of realistic



Sound Spatialization, Fig. 1 High-level acoustic components for VR auralization with focus on spatial room acoustics and headphone reproduction

sonic interaction of objects in motion with a geometric relationship in space.

On the other hand, a perceptually plausible and efficient auralization is forced to be preferred to an authentic rendering due to the limitation in memory and computational power related to low latency constraints. This trade-off is complex and challenging because, especially in VR, real-time constraints involve a multimodal system, thus requiring resources shared with graphics, sensors, application logic, and high-level functionality (e.g., artificial intelligence).

Reproduction

Immersive sound spatialization can be achieved through a speaker setup or headphones setup, with technical differences in the encoding phase and radical differences in perception for listeners. Entry "Virtual Reality: Headphones" discusses headphones sound playback that is the hardware solution available and easily integrated with head mounted displays (HMD) at customer level. In the following, a brief overview of both approaches is provided.

Headphone Reproduction

One of the main advantage of headphone-based reproduction is the complete control of sound synthesis and binaural cues arriving at each ear (left and right channels); high level of isolation from external and noisy environmental sounds, e.g., echoes and reverberation, in listeners' can be obtained by ear occlusion and noise-canceling technologies.

However, headphones may be experienced as intrusive by the user at the expense of naturalness and externalization of the listening experience, causing the so-called in-head localization where stimuli are heard inside the head, thus interfering with the natural outside-the-head localization of surrounding space (Shinn-Cunningham and Shilling 2002). Headphone-induced spectral coloration can be reduced by carefully following product design criteria and ad-hoc equalization algorithms with the aim of minimizing artifacts in the auralization.

Auralization with headphones requires head-related transfer function (HRTF) encoding and interpolation in a suitable functional basis, like in the spherical harmonic (SH) domain. A HRTF spatial grid of 4 5° spacing in both azimuth and

elevation with decreasing density above the head leads to a perceptually optimal representation for HRTF filters that could be convolved with partitioned block algorithm providing a compromise between computational efficiency and latency (Välimäki et al. 2016).

Loudspeaker Reproduction

In a loudspeaker reproduction, the rendered sound-field is completely extra-aural, thus naturally incorporating user acoustics in the so-called sweet-spot, i.e., the optimal listening area, which varies in size among techniques. Two main approaches can be considered (see Spors et al. 2013) for a detailed review on this topic):

1. Panning with level differences and/or time delays
2. Sound-field synthesis

The most common example of the first approach is the two-channel stereophony where the so-called panning law determines level/time differences in two loud-speakers in order to render virtual sources. The works by Pulkki formalize the vector-based amplitude panning in a multiple loudspeaker setup (Pulkki et al. 2018).

Sound-field synthesis employs a large number of loudspeakers to synthesize a virtual sound field within a listening area. These multiple channels are usually arranged at ear level as linear, circular, or spherical arrays defining the distribution of monopole sources used to compute the virtual secondary sources and the pressure field at an open area surface with a desired spatial sampling, i.e., aliasing frequency. Examples of such approach are wave-field synthesis, higher order ambisonics and their derivatives. It is relevant to note that human perception plays a critical role also in the design of the loudspeaker configuration and reproduction algorithms in order to guarantee a satisfactory perceived audio quality.

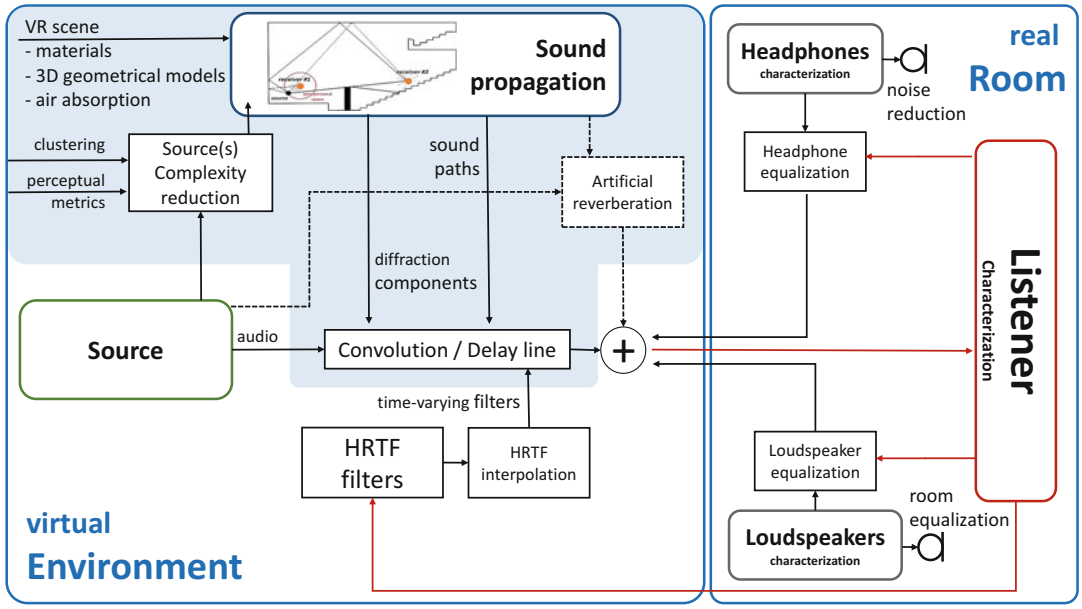
A critical aspect of loudspeaker reproductions lies in the acoustical properties of the playback environment that require room response equalization (RRE) algorithms able to remove echos and spectral distortions in the virtual sound field. Knowledge of single- or multiple-points of the room impulse response (RIR) inside the listening area is necessary to determine the most appropriate inverse filtering design able to compensate reflections and resonances of the environments (see Bharitkar and Kyriakakis (2006) for a review in this topic). Adaptive equalization is thus performed by optimizing signal processing approaches able to take into account the time-varying nature of the system, e.g., least-square solution, frequency warping, and multiple-input/multiple-output (MIMO) inverse theorem methods, to name but a few.

Auralization

The common and simple approach to provide an approximation of an acoustical space is by using a static RIR which could be convolved with an original dry signal; unfortunately, this method lacks of flexibility and it is inappropriate for VR. Rendering sound propagation for VR requires the spatialization of the directional RIR in the spatial room impulse response (SRIR).

Interactive auralization forces algorithms to cover most of the psychoacoustic effects in localization and timbre distortion due to dynamic changes of the active listening experience, thus defining memory and computational requirements (see Fig. 2 for a schematic block diagram). Given an encoding representation of the sound field, interactive VR latency requires the computation of SRIR in a convenient way: for instance, Schissler et al. (2016) performed the convolution in the spherical harmonics domain for HRTFs, sharing similar aspects to technologies for multichannel surround system such as high-order ambisonics, wave-field synthesis, and directional audio coding.

Sound propagation simulates the acoustics of the space, either a closed space such as a room or an open space surrounding the listeners (a complete survey in interactive virtual environments is provided in (Välimäki et al. 2016). One of the main challenges is the accurate modeling of sound propagation which is computationally intensive due to the multitude of reverberation



Sound Spatialization, Fig. 2 Block diagram of a typical system for sound spatialization and auralization. Both headphone and loudspeaker reproduction are displayed in the same diagram

paths from virtual sound sources to listener ears/listening area.

Perceptually motivated algorithms provide the control of computational resources, i.e., CPU and GPU processing, for SRIR computation, allowing a flexible scaling of aural complexity. For this reason, algorithms for dynamic spatialization of room acoustics allow immersion and externalization of a multiple sound source scenarios with configurable geometric complexity and implemented acoustic effects (i.e., order of reflections, diffraction, and scattering). Diffracted occlusion and sound propagation of early reflections should be coherently rendered in order to implement a perceptually plausible auralization.

Sound propagation modeling can be classified in three main approaches:

- Geometric methods, involving a high frequency approximation of sound propagating in the form of rays
- Wave-based methods, solving underlying physical equations
- Hybrid methods, mixture of approaches

Geometric Methods

Geometric techniques precompute spatial subdivision and beam tree data structures in order to provide real-time acoustic auralization of static sound sources. Modern algorithms support moving sources relying on an efficient ray-tracing which is shared with computer graphics (CG) (Cao et al. 2016); finding intersections between rays and geometric primitives in a 3D space allows the optimization of supporting data structures in computational cost and memory for a perceptually coherent auralization.

Wave-Based Methods

Wave-based methods are computationally expensive, requiring efficient solutions for real-time VR rendering. Savioja (2010) proposed a wave based simulation, combining finite difference methods and computation on the GPU. Mehra et al. (2015) described an interactive sound propagation system based on equivalent source method (ESM) for realistic outdoor sounds. This method extends previous researches where pressure fields are precomputing based on elementary spherical

harmonic (SH) description of the wave-based sound propagation in the frequency domain; high-dimensional acoustic field is compressing and allocated in memory for dynamic changing of sources/listener position and source directivity.

Hybrid Methods

Many hybrid solutions combining wave-based and geometric techniques exist. A valuable example is the work by Yeh et al. (2013) which proposed the precomputing of the pressure field in the near-object regions with numerical wave-based techniques and the modeling of sound propagation in the far-field with geometric propagation techniques.

Conclusions

Culling of inaudible reflections, limiting, clustering, and projecting reflections in the egocentric listener frame are required in order to increase the perceptual plausibility of the sound spatialization while keeping under control memory and computational cost (Hacihabiboglu et al. 2017).

The encoding of a virtual sound field require the parametrization of the perceptual fields in descriptors such as propagation delays, loudness, and decay times, ready to be quantized and compressed; the final aim of auralization techniques should be to find practical solutions on large, complex interactive scenes with millions of polygons (Raghuvanshi and Snyder 2014).

Finally, it has to be noticed that auralization of virtual outdoor environments is a challenging issue. Efficient algorithms rely on digital waveguide web connecting scattering junctions at nodes that represent discrete reflection points in the environment (Stevens et al. 2017). These algorithms extend the scattering delay network approach which was developed with particular attention to computer games (Hacihabiboglu et al. 2017).

Cross-References

- ▶ Immersive Visualizations Using Augmented Reality and Virtual Reality
- ▶ Overview of Virtual Ambisonic Systems
- ▶ Presence and Immersion in Virtual Reality
- ▶ Sonic Interactions in Virtual Environments
- ▶ Training Spatial Skills with Virtual Reality and Augmented Reality
- ▶ User Acoustics with Head-Related Transfer Functions

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Sound Synthesis

► Sonic Interactions in Virtual Environments

SoundScapes

► Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being

Spatial Audio and Sound Design in the Context of Games and Multimedia

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Synonyms

Localization; Sound design; Spatial processing; Spatialization

Definitions

Audio spatialization is referred to an audio processing algorithm by which one is able to create an impression of a virtual sonic source positioned in a specific location in a virtual context.

Introduction

Spatial audio plays a vital role in the design of a variety of multimedia presentations, especially virtual and augmented reality games. The brain processes sensory stimuli from both ears to analyze the surrounding sonic scene and detect the nature and position of sound sources as objects or as ambient sounds (Jan Schnupp and King 2012; Blauert 1996). The brain also analyzes the acoustical signature of the environment and makes inferences about the size of the environment and the materials comprising the environment.

Spatial audio algorithms provide mechanisms for composers and sound designers to consider such auditory cues when planning the experience and the narrative of an XR (augmented/virtual reality) game or a multimedia presentation. In traditional theatrical and cinematic contexts, the proscenium, camera angle, and lighting design all provide visual cues to define the focal point of the narrative and lead the attention of the audience members. Analogously, in the context of a game in which the player has the freedom to look and move around in three dimensions, 3D spatialized audio cues play an important role in supporting the narrative of the game and guiding the player's focus. This entry discusses a number of sound design strategies and audio spatialization techniques which are often used in audio production for games and other multimedia.

Sound Design and Spatial Audio

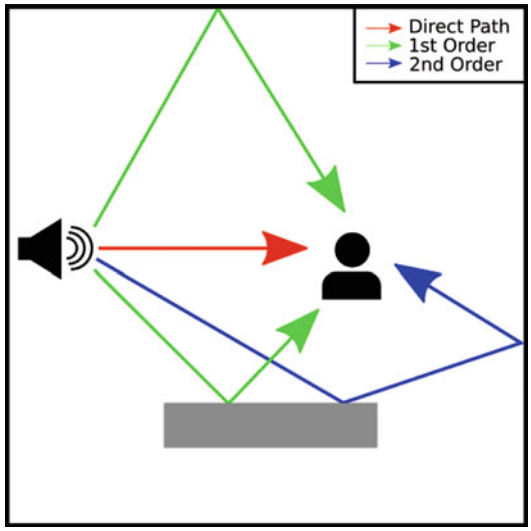
Sound design styles usually live on the spectrum of realistic versus abstract design. Realistic designs attempt to render diegetic sounds as realistically as possible, while abstract designs attempt to establish a sonic language to attach imaginative, emotional, or psychological meaning to specific sounds. Examples of diegetic sounds are the voice of characters in the story or sounds emanated by objects and their interactions in the scene. The acoustic character of the environment of a scene is implicitly defined by the rendition of the diegetic sounds given the geometry of space and objects in the scene. Examples of non-diegetic sounds are voiceovers, music, and abstract sound effects.

Sounds used in a game are often categorized in many different ways, and the designer has to make decisions about the spatialization of the sound and music based on a variety of parameters. When attending to the realistic aspects of the design, the spatialization of sounds should mimic physical effects of spatialization as much as possible. Spatialization of sounds need to happen in real-time in interactive games and some spatialization techniques may require considerable processing power. Therefore, a designer may choose to spatialize only some of the audio cues. Many aspects of spatialization techniques can be run in parallel and with the progress in computing technology, specifically in graphics processing units (GPU), spatialization of audio in more recent games is becoming more complete and lifelike. Generally, sound cues are separated in two distinct categories in regards to spatialization:

1. Sound Objects: these sounds are spatialized in real-time for the diffusion system used (speaker array, headphones, etc.) based on the position and head orientation of the player. Great emphasis is given to clearly depicting the proximity and direction of the objects in relation to the player, as well as to simulating the sonic effects of the objects' interaction with the acoustics of the virtual scene.
2. Ambient Sounds and Music: while these sounds may be spatialized, this step is often prepared in multichannel mixes (such as 5.1 mixes) which are in turn adapted to the diffusion system used. This approach requires less processing power for the spatialization process in real time.

Acoustics

Even though sounds propagate as waves in reality, for many applications including spatialization, and for understanding the interaction of a sound object with an acoustic environment, audio propagation is often modeled as emanation of sound rays. Some objects have specific frequency-dependent diffusion patterns (e.g., a speaking person emanates more sound towards the front than towards the back, especially more high-frequency sound). Figure 1 shows an example of different sound rays from a source arriving to a listener within an acoustic environment. In the interest of clarity, this figure is depicted in two dimensions; however, in reality and for synthesis of three-dimensional (3D) audio, one should consider this scenario in three dimensions. The direct ray arrives first and it is followed by low order reflections.



Spatial Audio and Sound Design in the Context of Games and Multimedia, Fig. 1 Examples of a direct ray, first and second order reflection paths

High-order reflections, which often fuse together as a diffused and decaying reverb sound, arrive last. Due to the Hass or "precedence" effect, the brain assumes that the source is located in the direction in which the first ray arrives to the listener (Haas 1972). Sound rays interact with boundaries and obstacles in the acoustic scene by reflection and diffraction. Sound rays are also filtered by the listener's body and ears, according to their anthropometric parameters. In order for a spatialization algorithm to create a realistic spatial impression, all of these physical effects must be simulated. The anthropometric parameters are discussed in the Binaural Processing section, and the interaction of the sources with the acoustic environment is discussed in the Acoustic Modeling section.

Diffusion Systems

Game audio can be diffused in various formats based on the capabilities of the game engine, computing hardware, and audio hardware. Designers need to consider both the technical and artistic aspects of these constraints. In some cases, the design may be flexible in supporting multiple diffusion formats.

Stereo

Stereo diffusion systems are by far the most prominent means of sound reproduction. These systems are designed for the playback of stereo audio signals, which consist of two channels referred to as *left* and *right* channels. In stereo diffusion, these channels are independently routed to loudspeakers placed to the left and right of a listener. The ideal speaker placement in this configuration is one in which the loudspeakers lie along a circle with the listener in the center, 30° off axis in either direction (Rumsey 2013). This configuration is typically accompanied by a subwoofer to accentuate the low frequencies of the audio; however, subwoofers are not necessary to achieve the stereo effect.

The stereo configuration allows for the perception of sound along a gradient of *left* to *right*. *Panning* refers to how present a sound is in either speaker with respect to its amplitude.

In stereo panning, often a *constant power* algorithm is used to make sure that, as a sound is panned from left to right, it maintains the same perceived volume and only changes in terms of its spatial location.

Surround Sound

Surround sound systems are diffusion systems which add additional speakers to a stereo configuration in order to create two or three-dimensional panning capabilities. The kinds of systems most commonly referred to by the term surround sound are 5.1 and 7.1 systems. In this notation, the first digit refers to the number of loudspeakers, and the second digit refers to the number of subwoofers. A standard 5.1 system includes two stereo speakers, a center channel, two "surround" speakers behind the listener, and a sub-woofer. A 7.1 system adds two "rear" speakers to a 5.1 system and shifts the surround speakers almost directly to the left and right of the listener. More recent systems add "top" speakers to create a sense of vertical displacement. These configurations are standard for movie and TV applications and can be adapted to both movie and home theaters. In academic settings, diffusion systems wherein speakers are evenly distributed along a circle, sphere, hemisphere, or polyhedron are commonplace and can accommodate three-dimensional panning.

Because of the variability between surround sound systems, surround sound audio is commonly rendered in either multiple formats or in a portable format that can be decoded to any given system. For example, the playback medium for a movie typically has stereo, 5.1, and 7.1 mixes to adapt to different home theaters. Spatialization techniques such as ambisonics, which will be discussed in detail later in this entry, store spatial audio information in a format which is independent of speaker placement and is thus highly adaptable to different configurations.

Headphones

Headphones are two-channel diffusion systems which sit on the ears of a listener and project sound directly into the tympanic cavity. Because headphones consist of two speakers, they are also well-suited to playback of stereo audio. Unlike loudspeaker systems, however, the acoustic qualities of a room are bypassed when listening to audio through headphones. This allows for the utilization of psychoacoustic effects to create a three-dimensional spatial image, which will be explored further in the discussion of binaural audio.

Audio Spatialization Techniques

Some spatialization techniques for speaker arrays such as wave field synthesis (Berkhout et al. 1993) and Moore's model (Moore 1983) control the amplitude and the delay of the signal over the multiple speakers. Other spatialization techniques such as Ambisonics (Gerzon 1975) and Vector Base Amplitude Panning (VBAP) (Pulkki 1997) control only the amplitude of the diffusion of audio signals for generation of spatial impressions. In the interest of brevity, the entry discusses only the Ambisonics technique, which is one the most prevalently used techniques, and the binaural rendering technique which is usually used for listening over headphones.

Ambisonics

Ambisonics recording technique (developed by Michael Gerzon in 1970s (Gerzon 1975)) has become prevalent in the field of professional and consumer three-dimensional audio. In its most basic format, this technique uses four directional microphones, positioned in a tetrahedron orientation, to record four audio signals, which are encoded to represent the three-dimensional sound pressure levels at the location of the microphone. This representation is in terms of the spherical harmonic components of the sound pressure field. Ambisonic decoding can be used to present the recorded media over a variety of audio diffusion system configurations including high fidelity loudspeaker configuration, and binaural reconstruction of the data for virtual and augmented reality equipment.

Figure 2 shows the orientation of the four microphones of a basic ambisonics microphone.

The signals from the four microphones are mixed as follows to obtain the B-format ambisonic signal:

$$W = LFD + RFU + LBU + RBD \quad (1)$$

$$X = LFD + RFU - LBU - RBD \quad (2)$$

$$Y = LFD - RFU + LBU - RBD \quad (3)$$

$$Z = -LFD + RFU + LBU - RBD \quad (4)$$

where LFD stands for left-front-down capsule, RFU for right-front-up capsule, LBU for left-

Spatial Audio and Sound Design in the Context of Games and Multimedia, Fig. 2 An ambisonic (soundfield) microphone with four capsules positioned in a tetrahedron configuration

back-up capsule, and *RBD* for right-back-down capsule.

A spatialized ambisonic signal from a mono source S could also be synthetically made with the following equations:

$$W = S * \sqrt{2} \tag{5}$$

$$X = S * cos(\theta) * cos(\phi) \tag{6}$$

$$Y = S * sin(\theta) * cos(\phi) \tag{7}$$

$$Z = S * sin(\phi) \tag{8}$$

where θ is the desired azimuth and ϕ the desired elevation for the spatial impression of the audio source S.

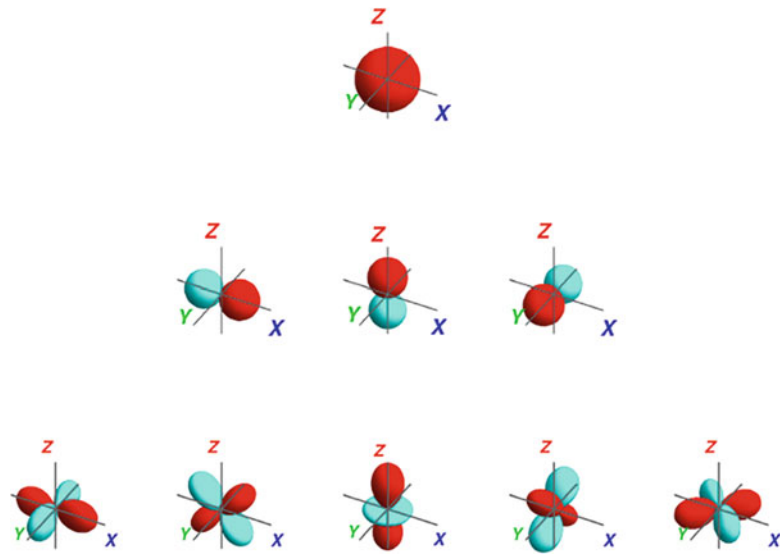
The W, X, Y, and Z in B-format represent the 0th and 1st order spherical harmonics shown in Fig. 3. Given a specific diffusion system, the decoding process works to decode the W, X, Y, and Z representations into signals appropriate for the chosen speaker orientation. Ambisonics technique provides a viable algorithm for diffusion of an Ambisonics recording in any speaker configuration. In other words, one will be able to present an ambisonic signal (recorded or synthesized) in many different venues with varying speaker configurations with little difficulty. One of the weaknesses of Ambisonics is that the spatial impression quickly deteriorates if one moves away from the sweet spot, but in the context of single-player games, this is not a shortcoming as long as the location of the player is always taken into consideration in the calculations.

Binaural

Binaural processing attempts to spatialize audio through headphones, or sometimes, through a set of stereo speakers. In everyday life, our brains interpret audio sources as pressure waves in the ear. The complex geometry of the pinna and ear canal act as an analog filter for the pressure waves before they reach the inner ear where the sound is transformed into neural information to our brain. Binaural processing attempts to characterize the physical (analog) filter given by the ear geometry into a digital filter.

Binaural Recording

The simplest form of binaural processing is to record audio sources using a torso-shaped mannequin with microphones placed inside silicone ears. The left and right ear microphones record a given



Spatial Audio and Sound Design in the Context of Games and Multimedia, Fig. 3 Spherical Harmonics of Order 0, 1, and 2

source as a stereo audio file which can then be played back to the listener through headphones. From the listener's perspective, the virtual source will be localized in the space where it was recorded.

Binaural Processing

One immediate downfall to binaural recording is the lack of listener input; wherever the original source was recorded relative to the mannequin is fixed and unchanging. It is possible to synthesize the binaural effect and account for the position and orientation of the listener in relation to virtual sources. Every position around the head produces a unique analog filter known as a Head Related Transfer Function (HRTF) for both the right and left ear (see Fig. 4).

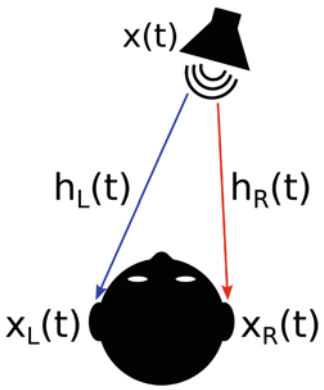
A virtual audio source can be spatialized using headphones if the audio signal is filtered using these position-dependent digital filters. The common method of implementing this spatialization technique is to record a set of impulse responses around the mannequin's head (called Head Related Impulse Response – HRIR). Each HRIR describes a digital filter given the location in space relative to the listener's head. Encoded in the digital filter are two major cues used for localization. The first cue is the *interaural level difference* (ILD) which characterizes the difference in sound level received by both ears. The other cue is the *interaural time difference* (ITD) which describes a time delay between each ear receiving the sound source. By performing convolution filtering of a mono audio source with both the left and right ear HRIR's, one can externalize and localize the audio source using headphones.

$$x_L(t) = \int x(t-\tau)h_L(\tau)d\tau \tag{9}$$

$$x_R(t) = \int x(t-\tau)h_R(\tau)d\tau \tag{10}$$

In this equation the signal that is to be spatialized is $x(t)$; the filters for the left ear and the right ear for the desired location in relation to the listener are represented by $h_L(t)$ and $h_R(t)$ respectively, and the signal that are diffused in the left and right ear of the listener are $x_L(t)$ and $x_R(t)$.

In binaural game audio, a specific HRIR is chosen and applied to the audio signal based on the position of a sound source in relation to player's position and head orientation. The player then hears the sound localized at the correct location and distance in the virtual world. It is also possible to produce a spatialization result with speakers by additionally implementing crosstalk cancellation between the speakers. While generic HRIR sets can produce fairly satisfactory results, each person possesses a unique set of HRIR. Modern binaural technologies include personalization of the applied HRIRs based on the player's various anthropometric data.



Spatial Audio and Sound Design in the Context of Games and Multimedia, Fig. 4 The source audio is filtered with an HRIR to produce the left and right ear versions of the signal

Acoustic Modeling

Acoustic modeling refers to the simulation of sound propagation in a virtual environment. While spatialization techniques can give the listener a sense of the angle and distance to the sound source, acoustic modeling allows the listener to hear the acoustical environment the sound is occurring in, by simulating how the sound interacts with room walls and other obstacles in the virtual environment. These obstacles cause two

key effects which must be simulated by acoustic modeling systems. First, sound reflects off obstacles, and low-order reflections are especially critical to the spatial impression (Bradley et al. 2003). Reflection simulation also includes simulation of sound absorption by the reflecting surface, which is often highly frequency-dependent. Second, sound diffracts around obstacles, which is readily apparent when sounds go around corners and behind obstacles (Svensson et al. 1999). Sound propagation can be accurately simulated with wavefield methods (Botteldooren 1995), but due to the enormous amount of computing power this requires, it is not presently a viable technique for real-time sound simulation in environments of nontrivial size. As a result, approximate models are used, with the quality dependent on the constraints of the application and the amount of available computing resources.

The most widely used acoustic modeling technique is reverberation, which simulates reflections and absorption in a generic enclosed room, usually using a convolution or a set of delay lines. Reverberation simulators typically only have a handful of parameters, such as the room size and the reflectivity of its walls, and as such can only give the listener a general sense of the size of the space. Nevertheless, reverberation has a very low computational cost and is even used in combination with more sophisticated techniques below to simulate very high-order reflections which are individually indistinguishable.

More complete acoustic modeling systems typically model sound propagation by rays. Approximating sound waves as rays is less straightforward than approximating electromagnetic waves (light) as rays in computer graphics, for two important reasons. First, the wavelength of sound is comparable to or even smaller than the size of obstacles, unlike in light simulation where the wavelength can be considered infinitely small in most cases. Second, information is usually encoded temporally on each sound "ray" – the original source sound signal – whereas an equivalent encoding in light rays is practically nonexistent in computer graphics. There are many approaches to modeling these wave effects with rays, and as a result, both the geometrical paths the rays traverse when reflecting and diffracting, as well as how this affects the resulting sound, differ substantially between acoustic modeling systems. These systems may also make different assumptions about the application, to trade off accuracy for computational complexity. For example, one common simplification is the assumption that the environment is a "shoebox" (axis-aligned rectangular prism), in which case diffraction does not play a role and reflection paths are easy to calculate. More sophisticated systems also exist which can handle scenes of arbitrary shape and complexity with moving obstacles.

Conclusion

Spatial audio can play an important role in game design. The directionality of audio can guide the listener's attention, and an ambient sound which is processed by a high-quality spatial algorithm can establish an effective sense of immersion for the player. High-quality acoustic modeling can greatly help the suspension of disbelief in establishing the virtual reality of the scene and interactive mechanisms within it. Designers need to consider and balance realism and detail against available processing power and player tracking sensors. Choosing artistic/narrative spatialization strategies and the optimal spatialization technique are important steps in the sound design process of a game.

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Spatial Augmented Reality Gaming

▶ Augmented Reality Entertainment: Taking Gaming Out of the Box

Spatial Cognition

▶ Foundations of Interaction in the Virtual Reality Medium

Spatial Hearing

▶ User Acoustics with Head-Related Transfer Functions

Spatial Interactions

▶ 3D Puzzle Games in Extended Reality Environments

Spatial Perception

▶ Virtual Reality: A Model for Understanding Immersive Computing

Spatial Perception in Virtual Environments

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Synonyms

Accommodation & convergence; Disorientation; Distance underestimation; Natural walking; Peripheral vision; Proprioception; Redirected walking; Stereoscopy

Definition

Virtual environments (VEs) are inherently spatial and afford the use of natural spatial senses to navigate. However, VEs are not perfect in this regard, and there are important spatial perceptual issues to consider.

Introduction

Virtual environments (VEs) are inherently rich sources of spatial information, as they are multisensory simulations of a 3D space. This is particularly true when a VE is experienced immersively through motion tracking and head-mounted displays or similar systems. Depending on the hardware being used, a VE can provide stereoscopic depth cues through a 3D display, motion parallax from head tracking, 3D spatial audio, and even directional haptic or temperature cues from fans or heat-lamps that simulate a breeze or the warmth of sunlight. Most importantly, immersive VEs can afford the ability for users to move and navigate naturally, which engages body-based spatial senses. Spatial sensing of VEs does have some important limitations, however, and can be intentionally manipulated by VE developers to achieve particular effects.

Human Spatial Senses

Vision is the dominant source of spatial perception in humans. One can visually perceive distant landmarks to stay oriented or get re-oriented (e.g., the sun or a tall building) or use nearby landmarks as beacons for navigation (e.g., a door). Humans also readily pick up depth and 3D structure from visual cues and optic flow patterns (Gibson 1979). Such visual cues are easily conveyed through VEs in 3D renderings and real-time visual feedback from motion-tracked movement.

Audition is another common source of spatial information in VEs. Spatial auditory cues can indicate from what direction a sound is emanating and its proximity. Doppler Effects can indicate if it is approaching or receding. The way sound bounces and echoes throughout the environment conveys information about the 3D structure and its materials. Positional spatial audio is relatively common in the game engines used to drive VEs. Physically accurate simulation of sound propagation is computationally expensive, however, and often only approximated.

Proprioception, or body-based senses, produces spatial feedback from various body parts to perceive posture and movement. Limbs and joints can determine how far one has walked or turned, and whether or not one is crouching. The inner ear can detect gravity and acceleration to measure spatial "uprightness" and balance or a sudden change in movement. The tilt of one's ankles can indicate slope. These senses are often intertwined with *idiothetic* cues, or an internal measure of one's intentions (i.e., "I meant to walk 2 m forward. How close am I?"). In the real world these are near-constant sources of spatial information, but they can be lacking or inaccurate in a VE. Indeed, the absence of proprioception can make it easy to become disoriented or lost in a VE, which may necessitate aids such as a minimap or in-game compass.

The specific type of navigation interface plays a large role here. Navigation via natural walking in large-scale tracking spaces provides full access to these senses (e.g., Waller et al. 2007), while navigation via a gamepad ignores them altogether. Most navigation interfaces fall in between. Walking on a VE treadmill provides nearly natural walking motions in the legs, for example, but nonnatural accelerations to the inner ear. Walking-in-place navigation often relies on gesture-like approximations of walking. Teleportation techniques often allow full movement and proprioception in a small area, but with disconnected jumps between places. In some cases, semi-natural navigation can inhibit spatial perception and task performance (Marsh et al. 2013), so care must be taken in designing the VE interface.

Haptic feedback is less common in VEs, but can support spatial perception. Humans can use a sense of touch to navigate through dark environments, feeling their way along to a destination. In a VE, users can reach out for a wall or other object expected to be nearby. Its presence or absence can confirm or deny one's sense of being in a particular location.

Spatial Mis-perception in VEs

Perception of space in VEs is not always perfect. Despite the wealth of spatial cues, users tend to massively underestimate distance in VEs by as much as one half (Renner et al. 2013). Thus, a user asked to toss a ball into a basket 10 m away will often toss it around 5–7 m and be surprised when it misses. This effect has been documented in a wide variety of tasks, but there is some evidence that users can quickly accommodate to the VE with a few minutes of interaction (Richardson and Waller 2005).

Users also tend to mis-perceive inaccurate movement in VEs as being accurate as long it is reasonably close (e.g., Jaekl et al. 2005; Steinicke et al. 2009). This is due largely to the imprecision in human nonvisual senses. In the real world, one's body monitors if it has turned approximately 90° and small misalignments can be fixed visually. In a VE, errors in motion tracking or intentional manipulations by the VE developer may cause physical and virtual motion to be unequal. For example, a user might have to rotate 115° physically to achieve 90° virtual rotation. As long as the user feels like they have moved approximately the right amount in approximately

the right direction, visual cues will dominate and the VE is perceived as spatially stable and accurate.

This perceptual flexibility can be leveraged to influence navigation through a technique called Redirected Walking (Razzaque 2005). Redirected walking subtly manipulates a VE to induce users to turn away from tracking boundaries (and physical obstacles) and back into open space. This enhances user safety and increases the size of VE that can be explored in a smaller tracking area, without compromising normal spatial perception.

Other considerations of spatial perception in VE include the effects of limited field-of-view (FOV) and the visual conflict between accommodation and convergence. In the latter case, users' eyes receive conflicting information when focusing on an up-close screen that simulates a distal virtual object. In the former case, potentially useful information in one's peripheral vision is not rendered due to the limited FOV of a display (often around 100°) relative to natural vision (>180°). This can affect users' ability to detect if they have passed a nearby object, for example. Real-world objects leave one's periphery when they are passed, but an equivalent virtual object would disappear sooner.

Cross-References

- ▶ Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology
- ▶ Locomotion in Virtual Reality Video Games
- ▶ Natural Walking in Virtual Reality
- ▶ Perceptual Illusions and Distortions in Virtual Reality
- ▶ Redirected Walking
- ▶ Sound Spatialization
- ▶ Training Spatial Skills with Virtual Reality and Augmented Reality
- ▶ Uncanny Valley in Virtual Reality

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Spatial Processing

▶ Spatial Audio and Sound Design in the Context of Games and Multimedia

Spatial Reasoning

▶ Training Spatial Skills with Virtual Reality and Augmented Reality
▶ World Representation in Artificial Intelligence

Spatial Recognition

▶ Training Spatial Skills with Virtual Reality and Augmented Reality

Spatial Room Acoustic

▶ Sound Spatialization

Spatial Room Impulse Response

► Sound Spatialization

Spatialization

► Spatial Audio and Sound Design in the Context of Games and Multimedia

Spatiotemporal Data

► Scalable Techniques to Visualize Spatiotemporal Data

Spatio-temporal Linear Logic

► Query-by-Gaming

Spatio-temporal Narrative Framework for Architecture in Video Games

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Definitions

Our existence is temporal and spatial. Therefore the design of time and space is essential in narrative. As a form of design work in which the production and consumption cycles entirely take place in a digital medium, video games can also give us new perspectives on the experiential and representational relationships of the physical architecture, especially in an age when the borders between physical and virtual are blurring gradually. This study intends to get inspired from frame-works of narrative, space and time discussed in various types of media like cinema, affiliating with architecture. Then an original analytic framework for spatial and temporal experience in video game spaces will be delivered. The framework, complementing and re-contextualizing narrative and architectural theories of Genette, Lynch, Norberg-Schulz and Nitsche from a multidisciplinary perspective; can be used for the analysis of the architectural experience in the video games spatially, temporally, narratively and phenomenologically.

Introduction

Architecture can be thought as interactive environmental-spatial storytelling. In video games, the interactive architectural space creates an atmosphere to be experienced by the human being from inside the cyberspace via a *digital persona* or *avatar*. Everything player experiences during a video game directly addresses to player's senses; through the visual and auditory inputs, the video game space creates the ambiance, spatial mood, and visually transferred tactile feelings. As developing technologies, like haptics, allow more human senses to be involved in this process, the relationship of video games and architecture gets more and more concrete.

Video games cannot be reduced to some of its components or properties because of their complexity and diversity. Thus, to get a richer picture of video games, a multidisciplinary approach with a wide spectrum covering different yet interconnected perspectives is needed. Following the call for an interdisciplinary approach, experiences of spatiality, temporality, and narrative in video games will be discussed drawing on many other disciplines such as literature, architecture, and cinema. Firstly, how time and space are structured in the narrative in general will be examined. Through a careful reading of narrative theory of different forms, and approaches of various disciplines for the video game, studies will help to form an original analytical framework. After an overview of the foundational concepts, the framework will be proposed as

a framework to analyze video games and create level breakdowns in game design documents.

Methodology

There were three main concerns during the development of an analytic framework for video games: The first one is not to restrict the approach to an architectural-only perspective in video games, given that architecture is just one of the key components of a video game. Analysis of architectural experience in video game spaces is more than a reading and classification of architectural elements in the video games. The second concern is, as explained previously that video games cannot be reduced to their components, the analytical approach should be deductive rather than inductive. The third concern is to define the scope of the work carefully, given that one single theory cannot be applied to all video games. The video games discussed in this work are limited to computer and console games with 3D environments and 3D navigation.

The existing frameworks for analyzing the space and time in interactive narratives are mostly derived from other narrative forms like literature or cinema. Getting nurtured from these existing frameworks, this study aims to complement and recontextualize narrative and architectural theories of scholars, like Gerard Genette, Christian Norberg-Schulz, Kevin Lynch, and Michael Nitsche, and finally deliver an original framework which can be used in the analysis of 3D adventure games.

This study follows these four steps:

1. *Literature review* on video games and architecture, focusing on spatiality, temporality, and narrative, are examined.
2. *Criticizing the existing models* in order to create a combined and complementary original framework.
3. *Developing the analytical framework.*
4. *Development of a pictographic visualization*.

Each category and element of the framework is visualized with distinct and memorable pictograms, which serve as an interface for the analysis.

Space and Time Studies in Video Game Narratives

All the good tales always begin with "once upon a time, in a land so far away" or "A long time ago in a galaxy far, far away. . .." Such introductory stock phrases clearly reveal two defining elements of stories as time and space. As Bridgeman put it: "Temporal and spatial relationships are essential to our understanding of narratives and go beyond the specification of a date and a location" (Bridgeman 2007). It is not different in the digital narratives and video games. In narrative theory, the temporality was discussed more than the spatiality (Wei et al. 2010). If the stories are considered as sequences of fictional events, space is always required for events to take place in a progression timeline. Digital narratives being more immersive and interactive than the other forms of narratives, space becomes a fundamentally defining component of them. Murray explains the importance of space in digital narratives in her own words: "The new digital environments are characterized by their power to represent navigable space" (Murray 1997).

The space not only provides a place for the story events but also evokes images in the players' minds. The spaces may have symbolic meanings so that they can address the audience's past experience and start to become a storytelling device. Lynch states: "Nothing is experienced by itself, but always in relation to its surroundings, the sequence of events leading up to it, the memory of past experiences"(Lynch 1960). Jenkins also emphasizes the importance of space in video games, where he calls the video game designers as "narrative architects" (Jenkins 2004). Therefore, the spatiality and temporality should be considered as an integrated complex of space-time in narrative.

In this chapter, a literature review on the space and time studies in narratives are given with this spatiotemporal approach. Only a few of these studies are specific to digital narratives, but a careful adaptation of the works on other types of narratives would be useful in the scope of this article.

Space in Video Games

Spatial research of this article traces the discourse of Nitsche's 2008 work *Video Game Spaces*, in which he cites Norberg-Schulz: "The existential purpose of building (architecture) is therefore to make a site become a place, that is, to uncover the meanings potentially present in the given environment" (Norberg-Schulz 1980). Therefore creating a space is a call for precision, complementation, and symbolization of the natural spaces. An understanding as such requires a thorough reading and comprehension of the space, which leads into spatial recognition and cognitive mapping (Nitsche 2008).

Written by urban planner Kevin Lynch, *The Image of the City* is one of the most influential books on mental maps of observers' comprehension of the city, in which he extracted five common elements to shape individual cognitive maps (Lynch 1960):

1. *Path* – linear axes, such as streets, trails, and other channels
2. *Edge* – edges with directional qualities, such as buildings and walls
3. *District* – relatively large sections of the cities, identified by its characters
4. *Node* – focal points and intersections
5. *Landmark* – identified elements that also serve as reference points

A spatial structure can be identified with more than one of these elements according to the observer's position, or the defining elements can change in different scales. A city that consists of many *districts* can be recognized as a *node* in a larger map. In a similar manner, a bridge can be considered a *path* for those who walk on it, a *landmark* for those who view it from afar, and a *node* for those who take photos of the panorama from the bridge at the same time.

Cristopher Alexander proposes a model consisting of 253 patterns in *A Pattern Language* (Alexander et al. 1977). Lynch's cognitive elements are able to create various patterns in different combinations, whereas Alexander's classification is rather stricter. In this sense, Lynch's approach would provide a more flexible model for reading the video game spaces.

Frank Ching, a professor of architecture who is known for his works on architectural design and graphics, is more focused on the visual properties of the *form*, *space*, and *order* in architecture. Providing geometrical schemes for spatial relationship and spatial organization, Ching then introduces six ordering principles: *axis*, *symmetry*, *hierarchy*, *rhythm*, *datum*, and *transformation* (Ching 2007). Ching's principles and schemes are mostly focused on the formation and transformation of the spaces, while Lynch's elements are related to the mental images that these forms evoke in the observer's mind.

Nitsche proposes three spatial structure typologies and a model for content assembly:

1. *Tracks and Rails* – axes that have directional values and define a movement.
2. *Labyrinths and Mazes* – a complex track open to exploration with rather less visual cues.
3. *Arenas* – open structures with a surrounding enclosure.
4. *Driven by Space* – in space-driven model, narrative and possibilities of engagement are directly built into the way spatial structures are assembled.

Nitsche's model creates a typological classification for video game spaces. Although it regards the operational and functional values of spaces, elements like *nodes*, *districts*, and *landmarks* are still missing from this model.

Murray discusses how the emerging digital technologies are reshaping the stories and what possibilities they promise for the future of narrative. While Murray discusses *agency*, she approaches the digital narrative spaces as *digital labyrinths*. She states that "Electronic environments offer the pleasure of orienteering in two very different configurations, each of which carries its own narrative power: the solvable *maze* and the tangled *rhizome*" (Murray 1997). Murray's division of digital environments is rather operational than visual. However, their

operational structure would inevitably reveal itself in the visual language of the story spaces.

In narrative theory, spatiality is often underrated and treated as a static component of the story (Wei et al. 2010). Zoran's model stands out by distinguishing three different levels of the structuring of space for the written narratives, which belong to the reconstruction of the world and "they are always perceived together, one through the other":

1. *Topographical level* – "space as a static entity"
2. *Chronotopic level* – "the structure imposed on space by events and movements" (projections of the interior on the bottom of the cube)
3. *Textual level* – "the structure imposed on space by the fact that it is signified within the verbal text" (Zoran 1984)

The layered approach on spatiality of narratives interconnected with the temporality is a peculiar one in Zoran's model. However being created for written narratives in 1984, this model does not respond to any technologic and interactive aspects of video game spaces. Compared with Nitsche's study, it has been observed that both of them consider the story space as a reconstruction in the audience's mind and regard the topographical qualities of the spatial component of a story. However, Zoran's model focuses on the dynamic relationship of space and time better than Nitsche's model, but lacks the way Nitsche's model corresponds to the interactivity and the stories and actions embedded in the spatial entities.

After examining all these existing models, it has been decided that a model for analyzing and creating video game spaces should focus on (1) spatial structures, (2) functionality, (3) interaction, and (4) audiovisual inputs.

Time in Video Games

The most common approach on time in narrative theory is to divide the temporal modes of narrative into two: (1) *story time (ST)*, the timeline in which the acts and events of the story take place, and (2) *discourse time (DT)*, time that passes by when the story is being told. To analyze the syntax of narratives, Genette uses five main concepts; the first three concepts of Genette are closely related with the temporality of a narrative:

1. *Order* – the relation between the order of events happened in ST versus they are presented in the DT
2. *Duration* – the relation between the duration of events in DT versus ST
3. *Frequency* – the relation between how many times the events happened in DT versus represented in ST (Genette 1980)

David Herman develops the concept of *fuzzy temporality* (Wei et al. 2010) to expand Genette's study which is based on bivalent tempi (Herman 2002).

Jesper Juul also adapts the temporal duality to video game time: (1) *play time* and (2) *fictional time* (Juul 2011). Based on Juul's time frames, Hitchens presents a new model for game time:

1. *Playing Time* – the objective real-world chronological time experienced by a player during and between play sessions
2. *Game World Time* – chronological time within the game worlds
3. *Engine Time* – the objective chronological real-world time in which a game engine executes
4. *Game Progress Time* – an abstract measure of time tracking movement toward game completion and allowing events to be related in terms of happening order (Hitchens 2006)

These compared temporal models mainly rely on the temporal duality of real time and fictive time. The models that use multiple time frames seem consistent in themselves. However, one might argue if they could be considered universal for video game times, since their temporal classifications are "somewhat arbitrary" and "are not clearly defined" (Wei et al. 2010). Genette's concepts of *order*, *duration*, and *frequency* seem promising for a video game-specific

Spatio-temporal Narrative Framework for Architecture in Video Games, Table 1 The spatial characteristics of the framework

	Spatial characteristic		Function in gameplay	Function in narrative
Structures		Paths and trails	Affects motions and operations Defines the orientation in the space	Affects the story structure
		Zones and platforms		
		Rhizomes and networks		
Functionality		Spatial repulsion	Helps to create navigation patterns Shapes the operational relationships Encourages the exploration of the spaces	Defines the spatial effects Alters the emotional experience Attributes meanings to the spaces
		Spatial appeal		
		Spatial puzzle		
Interactivity		Character interaction	Creates new operational possibilities Intensifies the gameplay	Increases the level of agency Enriches the story universe Develops the stories
		Object interaction		
		Navigation	Shapes the orientation patterns of the levels Locates the gameplay elements in the game space Creates variety in gameplay	Defines the location of the story Increases the player's agency
		Objectives and challenges	Defines the gameplay rules and mechanics Creates variation in the gameplay Creates the navigation patterns	Helps to create the plot Increases the level of agency Alters the emotional experience Attributes meanings to the spaces
Sensuousness		Perspective and camera	Enables empathetic immersion Defines the player's field of vision Ensures the continuity of the space Guides the player through game space	Defines the agency level of the player Alters the emotional experience Enriches the story universe
		Color	Shows the hostility of the environment Guides the player through challenges Creates the navigation patterns	Sets the mood Alters the emotional experience Increases the level of reality Enriches the story universe Defines the chronologic context Increases the effect of synesthesia
		Materiality		
		Sound	Gives hints about the environment Shows the hostility of the environment Guides the player Keeps the player interested	Sets the mood Alters the emotional experience Increases the level of reality Enriches the story universe Verbal storytelling

(continued)

Spatio-temporal Narrative Framework for Architecture in Video Games, Table 1 (continued)

	Spatial characteristic		Function in gameplay	Function in narrative
		Controls and body movement	Creates the link between the player and the in-game character Defines allowed motions and actions	Increases the level of agency Provides interactivity
		Interfaces	Sets the camera angles Helps to customize controls and configuration Provides essential gameplay information	Provides information

spatiotemporal model, but again, all the temporal frames need to be redefined and adapted for video games. Also, the aspect of *agency*, *flexible operational time*, and *selective order* of video game events needs to be added to the framework, which is going to be considered while developing the new framework.

Development of the Framework

The previous chapter remarks the importance of spatiotemporal approach and lists the existing models which could be utilized for a new analytical framework. The spatial and temporal characteristics of resulting combined analytical framework are listed in Tables 1 and 2.

Spatial Characteristics

The proposed framework for spatial characteristics is a rather hybrid and combined work which has a fourfold structure. Starting from the structure-only layer, each layer gets more interactive and perceptional elements involved than the layer before, creating a complete and evocative spatial environment when superposed in the end.

The four layers of the spatial characteristics are listed as:

1. *Structures* – the structural components of a video game.
2. *Functionality* – the functional meaning of a video game space reveals.
3. *Interactivity* – this layer is where the player's interaction with the space starts.
4. *Sensuousness* – in this layer, the players are inside the video game space via *avatars* or *personas*, and the reconstruction of the game world in their mind is created with the audio-visual sensory inputs of the spatial setting.

Temporal Characteristics

The proposed temporal model used in the framework is created considering the models explained in the previous chapter. Genette's ST and DT are redefined as (1) *playing time* and (2) *story time*. Considering the interactive dynamics and the flexible operational times of video games, two more spatial modes are added: (3) *game progress time*, the separate progression of game goals, and (4) *user created time (impromptu)*, the montage of story world events created by the player. Based on this narrative time frame, temporal characteristics of a video game are defined as (1) *sequence order*, (2) *narrative speed*, (3) *frequency*, and (4) *storytelling structure*. First three characteristics are adapted from three of Genette's concepts of narratology: *order*, *duration*, and *frequency* (Genette 1980), examining a previous adaptation of the theory to digital game storytelling made by Wei et al. (Wei et al. 2010). *Storytelling structures* are taken from Adams' classification of story structures (Adams 2010).

Pictographic Visualization

In the analytical framework, each spatial and temporal characteristic has three to six subcategories defining a typology or setting in the video games. These characteristics and subcategories are visualized with special pictograms designed for each title (Tables 1and 2). These patterns can lead to further analytical reading on which combinations can be considered more successful or which certain combinations enable what kind of impressions.

Spatio-temporal Narrative Framework for Architecture in Video Games, Table 2 The temporal characteristics of the framework

	Temporal characteristic		Function in gameplay	Function in narrative	Common forms in games
Sequence Order		Agent's choice	Increases player interaction	Increases the player's agency	Choosing between various objectives
		Flashback	Gameplay mechanic	Provides information Creates variety Expressive storytelling	Dialogue, cutscene, subtitles, screen caption, in-game texts, direct cut
		Flash-Forward	Gameplay mechanic	Provides information Creates variety Expresses storytelling	Dialogue, cutscene, subtitles, screen caption, direct cut
		Achrony	Provides side missions Alternative gameplay elements	Develops the story Increases agency	Choosing the order of side missions Skips
Narrative Speed		Scene	Increases the level of reality Immersive gameplay	Increases reality Immersive storytelling	Real-time mode
		Summary	Keeps the player interested	Succinct storytelling	Cutscene Voice-over Subtitle Direct cut
		Stretch	Gameplay mechanic	Creates variety	Cutscene Slow motion
		Ellipsis	Keeps the player interested	Succinct storytelling	Cutscene Voice-over Subtitle Direct cut
		Pause	Helps to customize settings Provides gameplay info Gives a break	Dramatic effect	Tutorial Cutscene Pause menu
Frequency		Singular	Keeps the player interested	Strong narrative	Event happens once
		Iterative	Keeps the player interested	Strong narrative	Recurring events shown once
		Repetitive	Practices a gameplay motif Progresses the player's skills	Creates variety in narrative	Repetition after illegal move or death Replaying the game

(continued)

Spatio-temporal Narrative Framework for Architecture in Video Games, Table 2 (continued)

	Temporal characteristic		Function in gameplay	Function in narrative	Common forms in games
		Multiple	Practices a gameplay motif Progresses the player's skills	Creates variety in narrative	Repeating gameplay motif
Storytelling		Linear	Increases the player interaction Provides alternative gameplays	Strong narrative Develops the story Creates variety in narrative Expressive storytelling Increases the player's agency	Single story with limited player effect on the plot
		Branching			Player choices develop the plot in different directions
		Foldback			Player's agency changes the direction of the story, but they fall back to inevitable key events
		Emergent			The player's agency can emerge unlimited storytelling possibilities

Conclusion

This article attempted to propose an analytical framework for the spatial and temporal characteristics in video games. The first question is: what architects can learn from the video games and how can the insights of this framework inspire them to shape the future of spatial environments with developing digital technologies? Another question is how this framework can be useful for video game designers? The framework was intended to be both an analysis and design tool. In the scope of this article, the framework was applied on single levels as case studies. If games are analyzed as a whole, and the pictographic pattern outputs of the analysis of different games are compared, the framework can illustrate repeating narrative and gameplay motifs visually. Such output can provide feedback for the designers for analyzing and designing video games.

Cross-References

- ▶ Narrative Design
- ▶ Narrative in Video Games
- ▶ Player Personas and Game Choice
- ▶ Player-Avatar Link: Interdisciplinary Embodiment Perspectives
- ▶ Scalable Techniques to Visualize Spatiotemporal Data
- ▶ Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation

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Spatio-temporal Querying

► Query-by-Gaming

Spear Phishing

► Anti-phishing Attacks in Gamification

Spectral Analysis

► UV Map Generation on Triangular Mesh

Speedrunning

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Synonyms

Speedrunning

Definition

Speedrunning is a self-imposed method of playing a game to complete the story or campaign as fast as possible. The most popular types of speedrunning are any % (completing the storyline while undermining the intended way to play the game), 100% (completing all game content before completing the storyline), and low % (completing the game with the least amount of progression possible).

Introduction

Speedrunning has had a cult following with dedicated players and viewership since the popularization of the Internet in the 1990s. However, its popularity during the pandemic lock down has made headlines and mainstreamed speedrunning into its own genre, ushering in influencers, streamers, and pro players who would try it out for themselves.

To create and submit your own speedrun is very straightforward. Record your gameplay while also complying with the rules as to what kind of speedrun you are pursuing: any %, 100%, or low %, as well as record your time with a graphical UI tool. Moderators of the speedrun.com will analyze and confirm if your speedrun is eligible for the category that you have chosen.

Origin

The origin of speedrunning is debatable. Some suggest DOOM was the first speedrun, while others believe speedrun started with Ocarina of Time or Super Mario Bros. There is really no correct answer because speedrunning is still relatively new compared to other traditional activities such as speedreading and distance running in Olympics. However, Drag Race (developed by Kee Games in 1977) prompted Activision to create their own game Dragster in 1980 (Carter 2018). Dragster then released a promotional event that challenged players to complete the game in under 6 s (Carter 2018). Video game enthusiast Todd Rogers completed the game in a record time of 5.51 s. Nevertheless, in 2017 a

computer scientist claimed it was mathematically impossible to achieve Roger's time (Carter 2018). The report stated the fastest time possible: 5.57 s. While Dragster was the first videogame to ever implement speedrunning fundamentals, it was not until the release of the Internet did speedrunning became truly popular with DOOM and QUAKE.

Appeal of Speedrunning

The 1990s and 2000s are heralded to be the "Golden Age" of gaming. There were no microtransactions. Innovative and creative genres were created, and many great games known today have taken inspiration from the foundations established in the 1990s gaming scene. The success of DOOM and QUAKE took the speedrunning community by storm due to one new in-game feature: being able to record one's own gameplay (Brewster 2019). Online forums became a hotspot for sharing speedruns and thus new gameplay categories were created. Any %, 100%, and low % were established and they are still the most popular categories to play today. However, these three popular categories are not the only ways to speedrun games. Games that offer specific mechanics can create their own special speedruns. For example, complete the Super Mario Bros game as "little Mario" using no power ups or special items. For another example, Nuzlockes were created in 1995 to create a higher level of difficulty while playing the Pokémon game (Brewster 2019). The appeal of the added challenges was to prove that the challenges could be met, and it turned out to be a spectacle for the viewers when it turned into a competitive speedrun.

Since QUAKE and DOOM are very fast-paced First Person Shooters (FPS), these titles became two of the classics to speedrun. The added perspective of first person along with the skill, mechanics, game knowledge, and time dedicated captured the interest of many even the newcomers to speedrunning. The same concept can be applied to other games such as Ocarina of Time, Golden Eye, and Super Mario Bros. Speedrunning often introduces new methods of playing a game or teaches the players/viewers something they did not know about the game. The word of speedrunning would soon spread further as the community would branch into streaming.

Fundraising for Charities

The popularity of Twitch and YouTube have spread the word of speedrunning to its own communities and those willing to dive into it. Eventually a community in Texas would take the initiative to create their own brand on Twitch and YouTube. In 2008, TheSpeedGamers held their first speedrunning marathon playing through all the Zelda games, with all proceeds donated to St. Jude Children's Hospital for a total of $1090 (Carter 2018). Not only was this one of the first fundraising events hosted by local gaming enthusiasts, but it also inspired the creation of Games Done Quick (GDQ), a biannual speedrunning marathon that does fundraising for charities.

Ever since its conception in 2010, there have been news headlines with GDQ's brand detailing their support for victims of natural disasters, amount of donations to charities, number of donors, and comments from viewers. As of January 2022, GDQ had completed 146 games, consistently peaked at 100 k viewers, and amassed 3.5 million dollars for the Malala Fund on the platform Twitch (GDQ.stats 2022). Organizations sponsored GDQ and the event won the support of other speedrunning organizations worldwide such as the European Speedrunning Association (ESA). Speedrunning's popularity in the 2010s would only be overshadowed by recent life-changing events that unfolded on the world stage.

Lockdown and Conclusion

COVID-19 had forced lockdowns around the world. People had different experiences coping with the separation of family, work, and friends.

Traditional sports were canceled, commuting to work was no longer an option, and public outings or meetings with friends was severely limited or outright banned. With everyone locked inside their homes, many people surfed the Internet and played video games. During 2020 in the midst of lockdown, Google's trending search picked up "speedrunning" that gradually increased over time, peaked at 100 in December 2020, and finally subsided in March 2021 (Huebl 2021).

Speedrunning has become as popular as the word gaming. YouTube influencers and Twitch streamers share their experiences with the speedrun genre on their respective platforms. Speedrun.com, a website used to submit and archive new speedruns, grew by 128 K registered speedrunners in 6 months after lockdown (Huebl 2021). GDQ's proceeds increased 40% from 2018 to 2022, from $2.1 million to $3.5 million (GDQ.stats 2022).

Speedrunning's tempo has amassed over the years, adding more to its community akin to a snowball effect. Down to its tightknit mechanics and exhilarating gameplay, speedrunning is here to stay.

Cross-References

▶ Underground Design of Kaizo Games

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Speedrunning in Video Games

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Synonyms

Any%; Clipping; Credit skipping; Lowest%; Random number generation manipulation; Routing; Sequence breaking

Definitions

100% = a speedrun category where speedrunners complete the game while getting every collectible or seeing every event. Some games have percent counters to signify when a game is 100% completed while other 100%s are chosen by community standards.

Any% = a speedrun category where speedrunners complete the game as fast as possible. Speedrunning = playing a video game as fast as possible by knowledge of specific routes needed to beat a video game.

Clipping = when two objects in a video game collide in unintended ways. Speedrunners can use clipping to pass through walls and barriers.

Credit skipping (also known as credit warping) = the act of using a glitch to start a video game's credits or ending sequence.

Lowest% = a speedrun category where speedrunners complete the game as fast as possible while doing the least amount of objectives. Some games have percent counters to signify when a game is at the lowest completion perfect while other game percentages are chosen by community standards.

Random number generation manipulation = referred to as RNG. The way a video game decides how random events occur. If a speedrunner has insight as to how a game is programmed, they can manipulate the game to their advantage.

Routing = the process of finding the fastest way to beat a video game.

Sequence breaking = performing actions in video games in ways unintended by the developers, typically earlier than usual.

Speedrunning

Speedrunning, in simplest terms, is completing a game, or parts of a game, as fast as possible. Players who speedrun are called speedrunners. Speedrunners record their runs to verify their time and to look for possible improvements. While the idea of beating video games quickly has existed since the advent of video games, the Internet has allowed players to create websites, forums, and communities dedicated to speedrunning. Nightmare Speed Demos is the earliest known website that hosted runs. It was created in 1996 in order to archive Quake speedruns.

Eventually, the site expanded to host speedruns of other games. Today, the largest website to catalog speedruns is Speedrun.com (Eva 2020).

With the advent of Youtube in 2005, speedrunning was able to grow in popularity as runs were more easily accessible to watch. Speedrunners also livestream their attempts as a way to record their runs while also adding an entertainment factor. Similarly, Twitch is another live streaming platform that has a large speedrun community. In 2011, Twitch was created as a separate category on Justin.tv but soon became more popular and the entire website was rebranded as Twitch in 2014. Speedrunners perform speedruns for their entertainment, to obtain a higher skill level for a game, or for a competitive aspect. Conventions are also another way the speedrunning community has grown in popularity. The earliest known speedrunning convention was Speedcon 2000 for the Quake community. The most widely known speedrunning convention today is Games Done Quick, where a weeklong marathon of speedruns are performed for charity (Gomez 2019).

Besides just playing at a faster pace than normal playthroughs of a game, speedrunners have extensive knowledge of what actions lead to the fastest way to completion. Routing is a term used to describe finding the best actions needed to complete the goal. Glitches are often used to skip cutscenes or sections of the game, allow for faster movement through areas, defeating enemies quickly, etc. Glitches that allow for players to skip directly to the game's credits are called credit skips. Glitches that allow the player to walk out of bounds are referred to as clipping. Perhaps one of the most famous speedrunning glitch is *Mario 64*'s Backwards Long Jump. Because *Mario 64* does not place a speed cap on backward momentum, players can perform long jumps backward on slopes to skip several parts of the game, such as the seemingly endless staircase, by gaining more momentum than intended by the developers. While not necessarily glitching, the act of sequence breaking is performing actions or events earlier than the game developers intended. In *Super Metroid,* the player can perform extremely precise jumps allowing Samus to reach new areas and collect several upgrades early. If a community knows enough about how a game is programmed, random number generation (RNG) manipulation can be used to ensure consistent results in areas where random events occur. For example, several games in the *Pokémon* franchise use RNG manipulation to ensure that their starting Pokémon has preferential stats.

Speedruns are separated in categories depending on the route. Any% is beating the game as fast as possible by any means. 100% is beating the game while getting all of the collectables, or anything else the community thinks is important. Lowest% is beating the game while doing the least amount of objectives. Glitchless, No Out of Bounds, and No Credits Warp are subcategories of the aforementioned categories that restrict using glitches, clipping, or credits warping, respectively. An example of a game that has a credits warp is *Pokemon Yellow*. In *Pokemon Yellow*, if the player resets the game while the game is attempting to save at a specific frame, the game will corrupt in such a way that it lets the player access the Pokemon menu option earlier than intended. With no Pokemon listed in the POKEMON menu, the player is able to scroll down below the normal sixth Pokemon slot. By

switching certain slots, the player can change the Item menu to behave similarly to the Pokemon menu by being able to scroll below the CANCEL button. From there, players will look for specific items in a list and manipulate them to switch the load zone from the player's house to the Hall of Fame, which will then start the credits sequence. With this trick, it is possible to beat *Yellow* in less than 1 min.

Individual Level runs refer to playing a certain level or part of a game, such as one track in *Mario Kart.* Speedrun communities make their own categories to fit what runs they find entertaining and/or competitive.

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Spheres Space

► Theory of Minkowski-Lorentz Spaces

Spheres, AABB, and OOBB as Bounding Volume Hierarchies

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Synonyms

Spheres, balloons, balls; AABB, Aligned-axis bounding boxes; OBB, Oriented bounding boxes

Definition

According to Ericson (2005), a bounding volume is a computational and geometrical structure constructed for enveloping one or more objects. It is used to simplify the representation of the objects and is widely used for collision detection. The most common bounding volumes are spheres and boxes; however, there are others enveloping structures as ellipsoids, cylinders, and polygons, among others.

Introduction

Bounding volume, which is the minimum enclosing volume for an object, is widely used for computational geometry. It is called an external representation because there is another internal representation: the internal containing volume which is the maximum volume contained into the object. The purpose of using the internal representation is to accelerate the time required to detect collisions for a pair of colliding objects, whereas the external representation is mainly used to decrease the time required to reject collision for a pair of non-colliding objects. Arcila (2011) performed a comparison with collision detector of public domain.

Bounding volume has been widely used. It has been focused on collision detection (Xiao-Rong et al. 2009; Chang et al. 2010; Zhigang et al. 2010; Dinas and Bañón 2015; Rong et al. 2019), object detection (Sun et al. 2020; Rubino et al. 2015), collision queries (Gottschalk 2000), urban cellular automata (Xia et al. 2020), and improving techniques (Chang et al. 2010; Arcila 2011), among others.

The bounding volumes selected to represent objects, respectively, in two and three dimensions were circumferences and spheres, Axis-Aligned Bounding Rectangles (AABR) and Axis-Aligned Bounding Boxes (AABB), and Oriented Bounding Rectangles (OBR) and Oriented Bounding Boxes (OBB). Several works were developed using double representation approach for specific bounding volumes, Arcila (2011); Dinas and Bañón (2015) reported an extensive review.

Bounding Volume Hierarchies

Spheres and Boxes are popular in bounding volumes literature, and they are widely used for collision detection. Spheres have two advantages mainly: (i) Their representation is simple for constructing and testing; however, for elongated objects its representation is poor on accuracy, and (ii) they are invariant for translation and rotations, and it means the representation is calculated at the first time and they do not have to be updated after translation or rotations of the objects. The boxes are straightforward to calculate and they are invariant to translations. OBB is invariant to rotation, however, AABB representatiion changes after rotations.

Several authors have been working on combining two and more bounding volumes, for instance, Arcila (2011) included in their work a double representation of bounding volume hierarchy (for spheres, AABBs, and OBBs): an external and an internal representation. The external bounding volume has been extensively used; it determines quickly nonintersection between a pair of bounding volumes, which consequently, accelerate the broad phase process. Analogously, the internal bounding volumes label quickly a pair of objects as colliding objects and accelerate the collision detection process. Additional research reports the combination of two or more bounding volumes; for instance, Rubino et al. (2015) documented for a sequence of images, the combination of ellipsoids and AABB for three dimensional shapes using scenarios open and close. Dinas and Bañón (2015) documented a brief review of bounding volume hierarchies and applications on collision detection.

Bounding Volumes Requirements

Bounding volumes have been researched for several authors, some of them are being focused on the importance, the techniques, the applications, the cost for construction, the minimal requirements, and the evaluation cost, among others (Zhigang et al. 2010; Chang et al. 2010). Several authors have been focused on the computational cost, then they developed several strategies to decrease it, and reported comparisons and techniques for the most significant bounding volumes, whereas others' works have dealt with the requirements (Chang et al. 2010; Weller 2013). Following are some requirements for bounding volumes:

- ***Tight fitting to improve the accuracy of objects representation:*** The bounding volumes have to be as tight fitting for the object as possible; however, it is impossible to know a priori the topology of the objects. In real scenarios, objects have several shapes; hence, it is difficult to unify a bounding volume that adjusts all the different shapes. Hierarchies help to approximate different objects, but they need more space to be stored.
- ***Efficient construction:*** The construction of a bounding volume depends on the complexity of the structure; it is computationally expensive for tighter fitting volumes (Nguyen 2006).
- ***Efficient updating:*** Bounding volumes should be updated after rotation and translation transformations; however, it is not necessary for those that are invariant to both transformations.
- ***Efficient overlap tests:*** Tests with low-computational cost belong to straightforward structures for bounding volumes; spheres and boxes are included, for instance; however, they are not tighter fitting. In contrast, tighter fitting volumes are computationally expensive for both creating and testing (Zhigang et al. 2010; Chang et al. 2010).
- ***The low usage of memory:*** The memory usage depends on the complexity of the bounding volume. For spheres and boxes, the memory usage is lower than other complex structures.
- ***Suitable for creating the hierarchy:*** Hierarchies divide the object into small parts, and they are used to decrease the cost of overlapping tests and increase the accuracy of the representation in lower levels.

Bounding Volume Hierarchies Requirements

Each bounding volume fulfills some requirements but not all of them, even though they are essential. To select a bounding volume, it is required to

identify the application. Nevertheless, to guarantee efficiency, Nguyen (2006) defined a set of requirements to apply hierarchies on bounding volumes:

- ***Volume Approximation:*** The representation of children nodes must improve, in fit, the representation of their parent; it means, children should be tighter fitting than their parent.
- ***Enveloped Area:*** Children nodes must envelope the same part of the object enveloped by their parent.
- ***Automatic Construction:*** Human iteration must not be required for hierarchy construction.
- ***High Degree of Accuracy:*** The original model should fit as tightly as possible for the bounding volume hierarchy.

Bounding Volumes Performance

The Eq. 1 can be used to evaluating the performance of the bounding volume (Chang et al. 2010; Weller 2013; Dinas and Bañón 2015).

$$T = NuCu + NvCv; \tag{1}$$

The cost function (T) measures the intersection between a pair of bounding volumes. Nu and N_v are the number of bounding volumes checking and updates performed during the traversal process of the hierarchies and the number of overlapping tests performed over the bounding volumes, respectively. In contrast, C_u, and C_v are the average cost of performance change in the bounding volume caused by the motion and the average cost of an overlapping test performed between a pair of bounding volumes, respectively.

However, Eq. 1 was extended by Weller (2013) to include primitives; thus, the Eq. 2 separates bounding volumes and primitives.

$$T = NuCu + NvCv + NpCp; \tag{2}$$

Only for primitives, the number of overlapping tests is represented by N_p, whereas C_p represents the average cost of overlapping tests performed between primitives. In Eq. 3, C_o represents any additional time required in the process. Usually, it is user for transformation updates or coordinates updates for the objects. Analogously, C_o is defined as a onetime processing by Ericson (2005).

$$T = NuCu + NvCv + NpCp + Co \tag{3}$$

For instance, values N_u and C_u are not used in Eqs. 1 and 2 because circumferences and spheres, in two dimensions, and OBRs and OBBs, in three dimensions, are invariant to rotation. In contrast, the N_v value increases. The separation of bounding volumes and primitives in Eq. 3 reduces the overlapping test performed over bounding volumes (N_v) for Eq. 2, but increases, for primitives, the number of overlapping tests (N_p).

If the bounding volume hierarchy is not enough to detect a collision between the objects, it is required to compare the faces of the objects by a face-face test (Arcila 2011), which is computationally expensive and, consequently, unsuitable for detecting collisions in real-time applications. For that, Eq. 1 ignores the difference between bounding volumes and primitives, while Eqs. 2 and 3 establish the difference by using N_p and C_p for number and cost of primitives, respectively, and N_v and C_v for number and cost of bounding volumes. Following is a short description of Circumferences, Axis-Aligned Bounding Rectangle (AABR), and Oriented Bounding Rectangle (OBR).

Spheres

It encloses a convex polygon in the minimal circumference; it is called bounding circumference by James and Pai (2004). An advantage of these bounding volumes is the efficient calculation of distances and intersections between a pair of circumferences. Although circumferences are invariant to rotations and translation, for elongated objects, they are not a good bounding volume.

For bounding circumferences, the error is the empty space – it means the area of the circumference without including the area of the polygon.

Contrarily, for containing circumferences, the error is the polygonal area without including the containing circumference. An intersecting approach to the BD-Tree or Bounded Deformation Tree (James and Pai 2004) worked with deformable models of rigid bodies. The hierarchy was tighter-bound than others and can be updated quickly after deformation.

The circumferences representation is extended to the three dimensional spaces, then the spheres are used to enclose the objects. Moreover, Chang et al. (2010) combined OBB and spheres to take advantage of the better of each one. A set of works has been developed around collision detection using double representations (Arcila 2011; Dinas and Bañón 2015).

Axis-Aligned Bounding Box (AABB)

An AABR is a minimal enveloping rectangle that covers the object. Key benefits include: (i) The rectangle can be calculated easily; (ii) the translation does not change the rectangle because it is invariant to translations; and (iii) a pair of rectangles can be tested in a low-computational cost. Nevertheless, the rotation of the object affects the rectangle, then a change in the bounding rectangle is required after each rotation. Like circumferences, the error of AABR is the area of the rectangle uncovered by the polygon.

The extension of AABR changes Rectangles for Boxes. An study on the average time for AABB under several assumptions was performed by Weller et al. (2006), in order to increase the understanding of running time for the bounding volume. In contrast, the double representation proposed by Arcila (2011) included AABBs. The error of containing rectangle is the area of the polygon uncovered by the containing rectangle. Zhigang et al. (2010) proposed a hybrid technique, which combined and took advantage of both, OBB and AABB – the compact representation of OBB and the efficiency of AABB to perform the overlapping tests. Finally, Xiao-Rong et al. (2009) proposed an improved method, which decreases the storage space, and consequently, the time for detecting collision. A tree structure is the hierarchy used for bounding volumes.

Oriented Bounding Box (OBB)

In two dimensions, using the polygon orientation, the minimal rectangle to fill the polygon can be calculated. The invariance to translation and rotations is the most significant advantage of this representation. Accordingly, after moving and rotating the object, it is not required to compute a new OBR, but only focus the work on the collision test, which is computationally more expensive than the AABR collision test. Additionally, Rubino et al. (2015) documented the combination between ellipsoids with AABB.

OBB were used in three dimensions not only as bounding volumes but also as containing volumes by Arcila (2011). The calculation of the error for bounding and containing volumes is similar. The bounding volumes error is the area of the volume unoccupied by the polygons; contrarily, the area of the polygon unoccupied by the containing rectangle is the containing volume error. Gottschalk (2000) worked on the creation of both, a data structure and an algorithm exact and efficient for general polygonal models using hierarchies of sphere, AABB, and OBB. The hierarchy representation used was the tree. As a conclusion, Gottschalk (2000) demonstrated that, asymptotically and in special conditions, OBBs are faster than spheres and AABBs. Jian-Hong et al. (2008) and several studies for OBBs worked on increasing the fitting of the bounding volumes and improving the tests for overlapping. They used the Convex Hull1 of the object to improve the fitting of the OBB, whereas a prejudgment strategy was used to accelerate the overlapping tests before using a traditional method. A simplified model for collision detection using OBB was proposed by Rong et al. (2019).

Finally, they used double bounding volumes; Zhigang et al. (2010) and Xia et al. (2020) combined the better of AABBs and OBBs, whereas Chang et al. (2010) took advantage of OBB, for their compactness, and from spheres, for their simplicity.

Conclusion and Discussion

Bounding volumes are used to encapsulate the objects; they are compounded by an internal containing volume to accept collision quickly and an external bounding volume to reject intersections quickly. Circumferences, Axis-Aligned Bounding Rectangles (AABR), and Oriented Bounding Rectangles (OBR) were selected to represent the objects in two dimensions, whereas Spheres, Axis-Aligned Bounding Boxes (AABB), and Oriented Bounding Boxes (OBB) were selected to represent three-dimensional objects. Objects were divided into smaller parts to approximate their shape and to minimize the error caused by the representation; in contrast, the hierarchy is the used data structure to locate the object partition into a tree.

The selection of the bounding volume deals with two facts: on the one hand, the simplicity of the representation; it helps to reduce the time required to construct the volumes and the space required for storing them. On the other hand, a bounding volume is required that fits the object tightly; however, it can be a complex selection for objects with different shapes.

Cross-References

- ▶ Bounding Volume Hierarchies for Rigid Bodies
- ▶ Collision Detection

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Spheres, Balloons, Balls

▶ Spheres, AABB, and OOBB as Bounding Volume Hierarchies

Sporting Life

▶ Online Gaming Industry Evolution, Monetization, and Prospects

Sports Game

▶ NBA 2K, a Brief History
▶ Rocket League: An Analysis

Sports Video Game

▶ Madden NFL and Infinite Inspiration

Star Wars Battlefront (2004), an Analysis

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Synonyms

First-person shooter; Video games

Definitions

First-person shooter (FPS)= a genre of games where the camera focuses on a gun (or other weapon) where the objective is to eliminate specific targets.

Introduction

Star Wars Battlefront, released in 2004, was developed by Pandemic Studios and published by LucasArts. The game was released on PC, Playstation 2, and Xbox. *Star Wars Battlefront* is the first game in the *Star Wars Battlefront* series, being followed by *Star Wars Battlefront 2*, and later being picked back up and remade by EA with the similar names *Star Wars Battlefront (2015)* and *Star Wars Battlefront 2 (2017)*. *Star Wars Battlefront* is a first and third person shooter that ran on the game engine Zero, and it had single-player and multiplayer capabilities. It has an ESRB rating of Teen. The game targeted anyone who enjoys large scale battles and anyone who is a fan of the Star Wars franchise as the game recreated battles on several key locations in the franchise.

Gameplay

Gameplay in *Star Wars Battlefront* is straightforward. Two teams are trying to do one of two things, either deplete the other teams reinforcement counter, which shows how many more soldiers they could call in, by killing enemies or capturing command points on the map. On every map, there are command points; they are certain zones that a team must capture by being inside the zone and then defend from the other team. On screen, there is a health bar, ammo, grenades, and a small mini map giving information on enemies and the positions of command points.

Star Wars Battlefront is fairly unique, and other than the fact that other games like Halo and Call of Duty are also first person shooters, there is not much similarity with other games. The exception to that is *Lord of the Rings: Conquest*, which was also created by Pandemic Studios, and is often criticized as being almost the exact same game. The only major differences are that Conquest is based around primarily melee combat while Battlefront is mostly ranged combat. The world of *Star Wars Battlefront* is made up from iconic planets from the Star Wars universe, such as Hoth, Geonosis, and Endor. Characters include the frontline troops for each faction, the CIS, Republic, Rebel Alliance, and the Empire, as

well as heros for the factions, such as Mace Windu and Count Dooku. *Star Wars Battlefront* only has three game modes. The first mode is Instant Action. It allows players to jump right into any battle you wanted. The other two modes are Galactic Conquest and the *Star Wars Battlefront* story mode, simply called Campaign.

Story

Weaknesses in Star Wars Battlefront come down to its lacking story mode, which left some players wanting more from its plot (Smith 2016). It was short and not put together in a story format, it is a mere series of battles. The public received Star Wars Battlefront (2004) well; it sold over four million copies by 2007 (Pham 2007). The biggest issue players had was a poorly done story mode, as it skipped around too much to form a coherent story and had players switching sides very often, causing the story mode to be confusing without other Star Wars media. Players praised the multiplayer modes and iconic scenes from the franchise. Ivan Sulic of IGN had praise for the games online mode, sound, and graphics while criticizing its single player for being too easy, incohesive, and having AI that "exhibits a type of intelligence roughly on par with the average rock's." They gave the game a score of 8.4/10 (Sulic 2004). Tom Bramwell of Eurogamer praised the game for showing the scale of what war would be like in the Star Wars universe while criticizing the optionality of battle objectives and win conditions (Bramwell 2004).

Microtransactions

The future games in the franchise changed direction along with a new publisher, Electronic Arts, or EA. EA decided to change several aspects of the game for its Battlefront and Battlefront 2, taking away a wide variety of maps for a smaller map pool, to which they only added on with DLC, and by removing several elements from the single player mode. EA also added microtransactions that undermined player progression, to the dismay of the playerbase (Scarpinito 2019). It is possible to achieve the same upgrades without purchasing microtransactions, but it takes a large amount of time and effort.

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StarCraft

▶ StarCraft Bots and Competitions

StarCraft Bots and Competitions

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Synonyms

Artificial intelligence; Competition; Game AI; Real-Time Strategy games; RTS games; StarCraft

Definition

Real-time strategy (RTS) games is a subgenre of strategy games where players need to build an economy (gathering resources and building a base) and military power (training units and researching technologies) in order to defeat their opponents (destroying their army and base). Artificial intelligence (AI) problems related to RTS games deal with the behavior of an artificial player. Since 2010, many international competitions have been organized to match AIs, or bots, playing to the RTS game StarCraft. This entry presents a review of all major international competitions from 2010 until 2015 and details some competing StarCraft bots.

State-of-the-Art Bots for StarCraft

Thanks to the recent organization of international game AI competitions focused around the popular StarCraft game, several groups have been working on integrating many of the techniques developed for RTS game AI into complete "bots," capable of playing complete StarCraft games. In this entry we will overview some of the currently available top bots and their results of recent competitions.

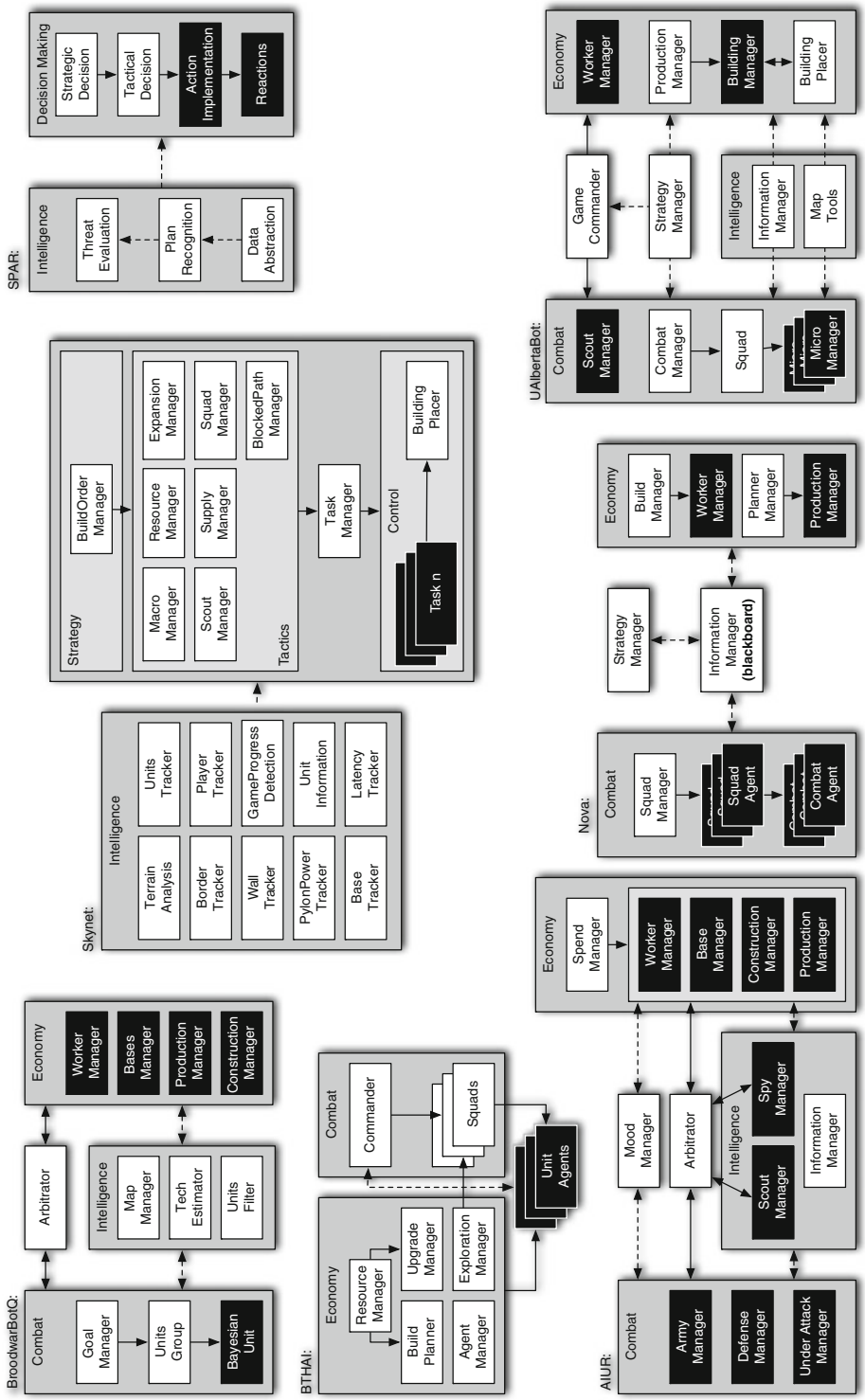
Playing an RTS game involves dealing with a wide variety of problems, ranging from micro-management problems such as unit control to macro-management problems such as resource allocation. A few approaches, like CAT (Aha et al. 2005), Darmok (Ontañón et al. 2010), or ALisp (Marthi et al. 2005), try to deal with the problem in a monolithic manner, by using a single AI technique. However, none of those systems aim at achieving near-human performance. In order to achieve human-level performance, RTS AI designers use a lot of domain knowledge in order to divide the task of playing the game into a collection of subproblems, which can be dealt with using individual AI techniques.

Figure 1 shows some representative examples of the architectures used by different bots in the AIIDE and CIG StarCraft AI competitions (see section "Synonyms"): BroodwarBotQ (Synnaeve et al. 2011), Nova (Uriarte and Ontañón 2012), UAlbertaBot (Churchill and Buro 2011), Skynet, SPAR, AIUR, and BTHAI (Hagelbäck 2012). Each box represents an individual module with a clearly defined task (only modules with a black background can send actions directly to StarCraft). Dashed arrows represent data flow, and solid arrows represent control (when a module can command another module to perform some task). For example, we can see how SPAR is divided in two sets of modules: *intelligence* and *decision-making*. Intelligence in SPAR has three modules dedicated to analyze the current situation of the game. Decision-making in SPAR is done through four hierarchically organized modules, with the higher-level module (*strategic decision*) issuing commands to the next module (*tactical decision*), which sends commands to the next module (*action implementation*), and so on. Only the two lower-level modules can send actions directly to StarCraft.

On the other hand, bots such as Nova or BroodwarBotQ (BBQ) only use a hierarchical organization for *combat* (controlling the attack units), but use a decentralized organization for the rest of the bot. In Nova and BBQ, there is a collection of modules that control different aspects of the game (workers, production, construction, etc.). These modules can all send actions directly to StarCraft. In Nova those modules coordinate mostly through writing data in a shared blackboard, and in BBQ they coordinate only when they have to use a shared resource (unit) by means of an arbitrator: a bidding market and broker for settling unit control; military and civilian groups/task forces bid for units proportionally to their usefulness and the task importance.

By analyzing the structure of these bots, we can see that there are two main tools being used in these integration architectures:

– *Abstraction*: complex tasks can be formulated at different levels of abstraction. For example, playing an RTS game can be seen as issuing individual low-level actions to each of the units in the game, or at a higher level, it can be seen as deploying a specific strategy (e.g., a "BBS



StarCraft Bots and Competitions, Fig. 1 Architecture of seven StarCraft bots obtained by analyzing their source code. Modules with black background sent commands directly to StarCraft, dashed arrows represent data flow, and solid arrows represent control

strategy" or a "Reaver Drop" strategy). Some bots reason at multiple levels of abstraction at the same time, making the task of playing StarCraft simpler. Assuming that each module in the architecture of a bot has a goal and determines some actions to achieve that goal, the actions determined by higher-level modules are considered as the goals of the lower-level modules. In this way, each module can focus on reasoning at only one level of abstraction, thus, making the problem easier.
- *Divide-and-conquer*: playing a complex RTS, such as StarCraft, requires performing many conceptually different tasks, such as gathering resources, attacking, placing buildings, etc. Assuming each of these tasks can be performed relatively independently and without interference, we can have one module focusing on each of the tasks independently, thus making the problem easier.

If we imagine the different tasks to perform in a complex RTS game in a two-dimensional plane, where the vertical axis represents abstraction and the horizontal axis represents the different aspects of the game (combat, resource gathering, etc.), abstraction can be seen as dividing the space with horizontal lines, whereas divide-and-conquer divides the space using vertical lines.

Different bots use different combinations of these two tools. Looking back at Fig. 1, we can see the following use of abstraction and divide-in-conquer in the bots:

- BroodwarBotQ (http://github.com/SnippyHolloW/BroodwarBotQ): uses abstraction for *combat* and divide-and-conquer for *economy* and *intelligence gathering*. To avoid conflicts between modules (since the individual tasks of each of the modules are not completely independent), BBQ uses an arbitrator.
- Nova http://nova.wolfwork.com/: is similar in design as BroodwarBotQ and uses abstraction for *combat* and divide-and-conquer for *economy*. The differences are that Nova does not have an arbitrator to resolve conflicts, but has a higher-level module (*strategy manager*), which posts information to the blackboard that the rest of modules follow (thus, making use of abstraction).
- UAlbertaBot (http://github.com/davechurchill/ualbertabot/): also uses abstraction in *combat* like the previous two bots. But it also uses it in *economy*: as can be seen, the production manager sends commands to the building manager, who is in charge of producing the buildings. This bot also uses divide-and-conquer, and tasks like scouting and resource gathering are managed by separate, independent modules.
- Skynet (http://code.google.com/p/skynetbot/): makes extensive use of both abstraction and divide-and-conquer. We can see a high-level module that issues commands to a series of tactic modules. The collection of tactic modules queue *tasks* (that are analogous to the abstract actions used in SPAR). Each different task has a specific low-level module that knows how to execute it. Thus, Skynet uses a three-layered abstraction hierarchy and uses divide-and-conquer in all levels except the highest.
- SPAR (http://www.planiart.usherbrooke.ca/projects/spar/): only uses abstraction. Its high-level module determines the strategy to use, and the tactical decision module divides it into a collection of *abstract actions*, which are executed by the lower-level modules.
- AIUR (https://github.com/AIUR-group/AIUR): is mainly divide-and-conquer oriented, with a slight abstraction on *economy* due to a Spend Manager deciding how to spend and share resources among Base, Production, and Construction Managers. At the beginning of a game, the Mood Manager initializes a "mood" which will influence both tactics and strategy. *Combat* is divided into three independent managers: the *Defense Manager*, controlling military units when there is nothing special; the *Under Attack Manager*, activated when the opponent is attacking our bases; and the *Army Manager*, taking control of units when it is time to attack, following a timing given by the current mood. This bot does not manage however any kind of reactive controls so far.

– BTHAI (https://github.com/jhagelback/oppri mobot): uses a two-tier abstraction hierarchy, where a collection of high-level modules command a collection of lower-level agents in charge of each of the units. At the high level, BTHAI uses divide-and-conquer, having multiple high-level modules issuing commands to the lower-level units.

Additionally, except for BTHAI, all other agents use divide-and-conquer at a higher-level bot design and divide all the modules into two or three categories: *intelligence gathering* and *decision-making* (sometimes divided into *combat* and *economy*).

Some bots using divide-and-conquer assume that each of the modules can act independently and that their actions can be executed without interference. BBQ, UAlbertaBot, and AIUR, however, use an arbitrator (*Game Commander* in UAlbertaBot) that makes sure that modules do not send contradictory orders to the same unit. However, very little bots handle the problem of how to coordinate resource usage among modules, for instance, BTHAI uses a first-come-first-serve policy for spending resources, and the first module that requests resources is the one that gets them. Nova and Skynet are exceptions and implement some rudimentary prioritization based on the high-level strategy. Following available resources and timing, AIUR's *Spend Manager* orders Base, Production, and Construction Managers what they have to build/produce. It also orders to start tech research and upgrades. The idea here is not to let the different managers allocate the resources they want, but to do the opposite, that is, finding how the AI can spend the available money.

One interesting aspect of the seven bots described above is that, while all of them (except AIUR) are reactive at the lower level (reactive control), most, if not all, of them are scripted at the highest level of abstraction. BTHAI reads build and squad formations from a predefined script, Nova's *Strategy Manager* is a predefined finite-state machine, BBQ's construction manager reads the build order from a predefined script, and Skynet's *Build Order Manager* is basically a predefined script. Such scripts describe the strategy that the bots will use; however, such strategy is always fixed. One could see this prescripting as if each bot defined a "high-level programming language" to describe StarCraft strategies, and the bots themselves are just interpreters of such strategy. Compared to current approaches for Chess or Go, this scripting seems rigid and inflexible, but responds to the much higher complexity of the StarCraft game. An interesting exception to that is UAlbertaBot, which uses a search algorithm in the *Production Manager* to find near-optimal build orders. Another interesting case is AIUR, which uses a *Mood Manager* to randomly pick a mood among six (cheese, rush, aggressive, defensive, macro, fast expand), which will influence the build order, strategy, and tactics.

In conclusion, we can see that there are two basic tools that can be used in an integration architecture: abstraction and divide-and-conquer, which are widely used by the existing StarCraft bots. For space reasons, we do not include an exhaustive comparison of the architectures of all the participating bots. Some more bots than the ones described here have been documented by their authors, such as SCAIL (Young et al. 2012b) or QUORUM (Young et al. 2012a). Let us now focus on their performance in recent competitions.

Recent StarCraft AI Competitions

This section reviews the results of three recent international competitions on AI for StarCraft. These competitions have been possible thanks to the existence of the Brood War Application Programming Interface (BWAPI) (https://github.com/bwapi/bwapi), which enables replacing the human player interface with C++ code. The following subsections summarize the results of StarCraft AI competitions colocated with two scientific conferences – AIIDE (Artificial Intelligence for Interactive Digital Entertainment) and CIG (Computational Intelligence in Games) – and one stand-alone competition called SSCAIT (Student StarCraft AI Tournament), during the past years. Since 2011, the CIG and AIIDE competitions have typically been held in August/

September in each year, as the conferences are scheduled quite close to each other, and SSCAIT has been held in December/January. As a consequence of this, AIIDE and CIG competitions share a big portion of the entrants.

AIIDE

AIIDE 2010. Started in 2010, the AIIDE StarCraft AI Competition (http://www.StarCraftAICompetition.com) is the most well-known and longest running StarCraft AI Competition in the world. Each year, AI bots are submitted by competitors to do battle within the retail version of StarCraft: Brood War, with prizes supplied by Blizzard Entertainment.

The first competition in 2010 was organized and run by Ben Weber in the Expressive Intelligence Studio at the University of California, Santa Cruz (http://eis.ucsc.edu/StarCraftAICompetition). Twenty-six total submissions were received from around the world. As this was the first year of the competition and little infrastructure had been created, each game of the tournament was run manually on two laptop computers and monitored by hand to record the results. Also, no persistent data was kept for bots to learn about opponents between matches.

The 2010 competition had four different tournament categories in which to compete. Tournament 1 was a flat-terrain unit micromanagement battle consisting of four separate unit composition games. Of the six competitors, FreSCBot won the competition with Sherbrooke coming in second place. Tournament 2 was another micro-focused game with nontrivial terrain. Two competitors submitted for this category, with FreSCBot once again coming in first by beating Sherbrooke.

Tournament 3 was a tech-limited StarCraft game on a single known map with no fog-of-war enforced. Players were only allowed to choose the Protoss race, with no late-game units allowed. Eight bots faced off in this double-elimination tournament with MimicBot taking first place over Botnik in the final. As this was a perfect information variant of StarCraft, MimicBot adopted a strategy of "mimic its opponent's build order, gaining an economic advantage whenever possible" which worked quite well.

Tournament 4 was the complete game of *StarCraft: Brood War* with fog-of-war enforced. The tournament was run with a random pairing double-elimination format with each match being best of five games. Competitors could play as any of the three races, with the only limitations in gameplay being those that were considered "cheating" in the StarCraft community. A map pool of five well-known professional maps were announced to competitors in advance, with a random map being chosen for each game.

Results are shown in Table 1. The team that won was Overmind (http://overmind.cs.berkeley.edu), from the University of California, Berkeley. Using the Zerg race, their strategy was to defend early aggression with zergling units while amassing mutalisk units, which they used to contain and eventually defeat their opponents. The mutalisk is a very fast and agile flying unit which is able to attack while moving with no drawback, which makes them quite a powerful unit when controlled by a computer. Overmind used a potential field-based micromanagement system to guide their mutalisks, which led them to victory. Krasi0 came in second place with a standard defensive Terran opening strategy that transitioned into "mech" play in the late game.

AIIDE 2011. In 2011 the University of Alberta hosted the competition, with organization by Michael Buro and David Churchill (https://skatgame.net/mburo/sc2011/). Due to a lack of entrants in tournament categories 1–3 in the 2010 competition, it was decided that only the full game category would be played in the 2011 competition, with 13 entrants. Another important change in the 2011 competition was the introduction of automated tournament managing software running StarCraft games simultaneously on 20 computers, allowing a total of 2340 games to

StarCraft Bots and Competitions, Table 1 Ranking of the three best bots of the AIIDE 2010 competition

Rank	Bot
1	Overmind
2	Krasi0
3	Chronos

be played in the 5 days that the tournament ran. This increase in games played also allowed the tournament to switch to a round-robin format, eliminating the "luck" factor of the pairings inherent in bracket-style tournaments. The bot that achieved the highest win percentage over the course of the competition would be determined the winner. Also, the competition became open-source, in an effort to prevent possible cheating and to promote healthy competition in future tournaments by giving newcomers and easier entry point by basing their design off of previous bots. All maps used by the competition were known long time by advance, so participants can test their bot on them. These ten maps remain the same for all AIIDE competition, from 2011 until the last one at the time this chapter has been written in 2015. Maps are *(2) Benzene*, *(2) Destination*, *(2) HeartbreakRidge*, *(3) Aztec*, *(3) TauCross*, *(4) Andromeda*, *(4) CircuitBreaker*, *(4) EmpireoftheSun*, *(4) Fortress*, and *(4) Python*. The number between the parentheses is the number of possible start points.

In the end, Skynet won the competition with its solid Protoss play (results are summarized in Table 2). The bot executed one of a small set of strategies randomly at the start of the match based on the map and the race of the opponent. Skynet would then amass a medium- to large-sized army and expand before moving out to attack. Good use of Dragoon (powerful ranged ground unit with clumsy movement) range and kiting micromanagement allowed it to hold off the early aggression of other bots such as UAlbertaBot, which came in second.

UAlbertaBot used an early Zealot rush strategy to take advantage of the power of early-game Protoss units. It would send out the first Zealots that were made and immediately attack the enemy base, using a unit counting heuristic to determine whether or retreat or keep pushing. Of note is that UAlbertaBot used an online planning algorithm to construct all of its economic build orders (Churchill and Buro 2011), as no hard-coded build orders were used.

StarCraft Bots and Competitions, Table 2 Results of the five best bots of the AIIDE 2011 competition

Rank	Bot	Win %
1	Skynet	88.9
2	UAlbertaBot	79.4
3	AIUR	70.3
4	ItayUndermind	65.8
5	EISBot	60.6

AIUR also chose Protoss, with a strategy that was in between Skynet and UAlbertaBot in terms of attack timings. At that time, AIUR chose one mood among five (leading to slightly different strategies and tactics) at the beginning of a game and kept it until the end. These five moods were (1) Rush: the bot tries early attacks and has good probabilities to send the two or three first Zealots (basic contact attack ground unit) to harass the opponent. (2) Aggressive: it has less chance to perform harasses with the first Zealots, and the first attack is usually a bit delayed with regard to the Rush mood. (3) Macro: the AI do not try any early attacks and focus a bit more on its economy before attacking. (4) Defense: AIUR "turtles" and wait to have a consequent army before running an attack. (5) Fast expand: the first building constructed it a base expansion, for a very economy-oriented game. Notice that build orders are not fully hard-coded since they can be altered by AIUR's Spend Manager.

Of note in these results was that a rock-paper-scissors effect happened among the top three finishers. Of the 30 rounds, Skynet beat UAlbertaBot 26 times, UAlbertaBot beat AIUR 29 times, and AIUR beat Skynet 19 times. Another notable result is that Overmind did not choose to compete despite winning the 2010 competition. After the competition, many bot programmers (including the Overmind team) realized that their 2010 strategy was quite easily defeated by early-game rushing strategies, and so they submitted a Terran bot instead, called Undermind, which finished in seventh.

AIIDE 2012. The University of Alberta also hosted the 2012 competition, with the major difference from the 2011 competition being the addition of file reading and writing for learning. Bots could now write information to disk during a match and then read the information during other matches, allowing them to adjust strategies based

StarCraft Bots and Competitions, Table 3 Results of the five best bots of the AIIDE 2012 competition

Rank	Bot	Win %
1	Skynet	84.4
2	AIUR	72.2
3	UAlbertaBot	68.6
4	BroodwarBotQ	59.1
5	AdjutantBot	52.8

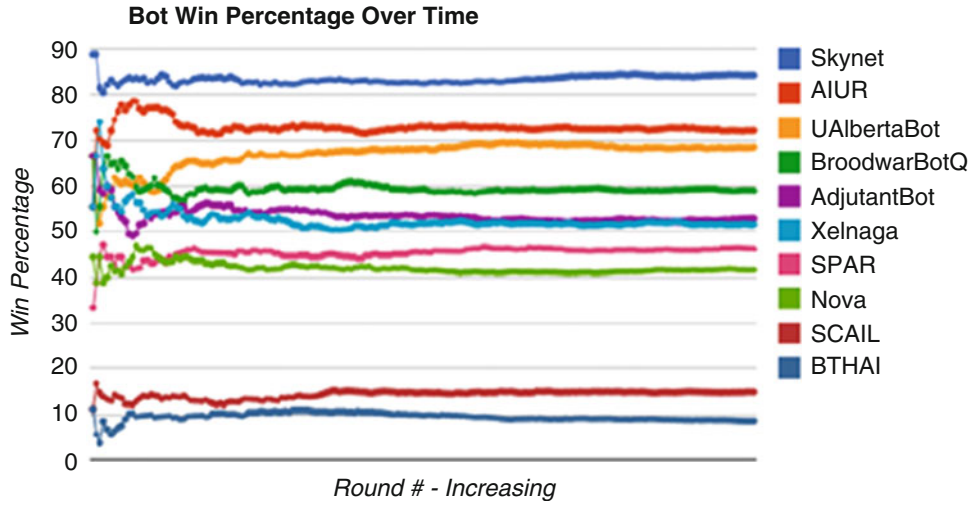
on previous results. Six of the ten entrants used this feature to aid in strategy selection, including the top four finishers. More improvements to the tournament environment also meant that a total of 8279 games could now be played in the same time period. Results are shown in Table 3.

Skynet once again won the competition with its solid Protoss build orders and good Dragoon kiting. AIUR and UAlbertaBot switched positions from the previous year to come second and third, respectively. Both AIUR and UAlbertaBot used data stored from the results of previous games to select a strategy for future matches. UAlbertaBot did this using the UCB (Auer et al. 2002) algorithm, while AIUR used a uniform distribution to choose its mood before altering this distribution after some games against the same opponent to favor efficient strategies, achieving similar results than UAlbertaBot. Notice that, compared to AIIDE 2011, AIUR proposes a new mood, *Cheese*, implementing a Photon Cannon rush strategy in order to surprise the opponent and to finish the game as soon as possible. The effect of this strategy selection process can be seen Fig. 2 which shows bot win percentages over time. While the earlier rounds of the tournament fluctuated wildly in results, eventually the results converged to their final values. One of the main reasons for this is due to the bots learning which strategies to use as the tournament progressed.

AIIDE 2013. A total of eight bots competed in the 2013 AIIDE competition with many of the same names from the 2012 competition, and some key updates were made to existing bots for 2013 which shook up the results from the previous years. A total of 5597 games were played during the 5-day tournament. UAlbertaBot took first place with a dominant 84.49 % win rate, with Skynet in second with 72.77 % (Table 4). The major addition to UAlbertaBot was a combat simulation package called SparCraft. UAlbertaBot was reengineered so that it now always attacked from the first combat unit created, using the SparCraft system to simulate whether or not the bot could fight against known enemy units, retreating automatically if it thought it could not. This addition, combined with some additional bug fixes, led to the victory. Skynet and AIUR both implemented strategy learning in 2013, which is evident from three in which both Skynet and AIUR's win percentage over time climbs dramatically from the first few rounds of the tournament to the later rounds. Ximp unfortunately crashed all games on the Fortress map and lost 10 % of its games for free as a result, which meant it could have possibly came in second place if not for all those crashes (Fig. 3).

AIIDE 2014. The 2014 AIIDE competition saw 18 total entrants, over double the number from the 2013 competition. This dramatic increase in numbers was partially because of a large advertising effort by competition organizers, combined with the inclusion of all the 2013 competition entrants (if they had not resubmitted new versions). UAlbertaBot and Skynet who finished first and second the year before were not updated in 2014 and so their previous versions were resubmitted. Along with the larger registration numbers came a lot of new Terran bots, a welcome change from the Protoss-dominated fields of previous years. The tournament managing software also underwent some major updates in 2014, allowing for faster game scheduling and the easy pausing and resuming of tournaments, resulting in 10251 total games being played, which was almost double the amount of 5579 from the previous year.

The results of the 2014 competition were dramatically different from previous years (Table 5). Since 2011 the top three bots in the AIIDE competition had been some permutation of Skynet, UAlbertaBot, and AIUR, and in 2014 the top 3 finishers were all completely different. In first place was ICEBot with a win rate of 85.85 %, which had a complete overhaul in terms of strategy and tactics from the previous year. ICEBot



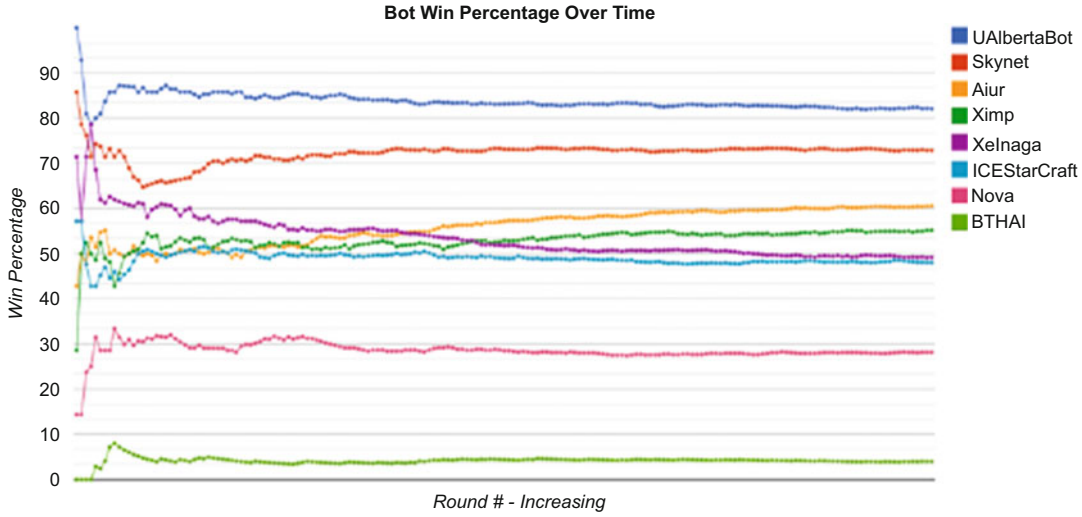
StarCraft Bots and Competitions, Fig. 2 Evolution of the win percentage of each bot participating in the AIIDE 2012 competition

StarCraft Bots and Competitions, Table 4 Results of the five best bots of the AIIDE 2013 competition

Rank	Bot	Win %
1	UAlbertaBot	84.49
2	Skynet	72.77
3	AIUR	58.51
4	Ximp	56.57
5	ICEStarCraft	48.53

had several strategies which it could implement, most starting with an early bunker defense and transitioning into attacking once a set of heuristics conditions had been met. ICEBot's source code was originally based on AIUR's modular design and changed to play the Terran race. In a close second place finish was Ximp – which had fixed the crashes and logic errors which had plagued it the year before. Ximp implemented a solid forge-first fast expansion strategy which transitioned into late-game carrier play. By building a large amount of early photon cannons in its expansion, Ximp was easily able to stop most of the early rushing bots, holding them off until its carriers cleaned up in the late game. Third place was taken by LetaBot, a new Terran bot whose source code was written on top of the 2012 version of UAlbertaBot and changed to play the Terran race. LetaBot implemented a number of strategies including a "cheesy" but strong bunker rush strategy which killed many bots very quickly, as well as a Wraith (mid-game flying unit) strategy.

AIIDE 2015. The 2015 AIIDE competition was the largest competition to date hosted by a conference, with 23 total bots competing. The competition environment was also changed so that the tournament was now run on virtual machines instead of physical machines. Doing this enabled the tournament to run for a full 2 weeks instead of the normal 1 week, resulting in a total of 20788 games being played – 90 full round robins between each bot pairing. 2015 saw the most even distribution of race selection ever in a StarCraft AI competition, with five new Zerg submissions along with seven Protoss bots and nine Terran bots. The first ever Random race entry was also submitted as UAlbertaBot had been updated to play all three of the available races. When playing Random race, StarCraft randomly assigns one of Protoss, Terran, or Zerg after the game has started, with your opponent not knowing which race you are until they have scouted you on the map. This provides a significant advantage as the enemy's initial build order must now have a period of uncertainty during which is has to guess what race it is playing against.



StarCraft Bots and Competitions, Fig. 3 Evolution of the win percentage of each bot participating in the AIIDE 2013 competition

StarCraft Bots and Competitions, Table 5 Results of the five best bots of the AIIDE 2014 competition

Rank	Bot	Win %
1	ICEBot	85.86
2	Ximp	84.64
3	LetaBot	82.09
4	AIUR	70.94
5	Skynet	68.74

StarCraft Bots and Competitions, Table 6 Results of the five best bots of the AIIDE 2015 competition

Rank	Bot	Win %
1	Tscmoo	88.52
2	ZZZKbot	87.84
3	Overkill	80.69
4	UAlbertaBot	80.20
5	AIUR	73.02

The results of the 2015 competition were extremely close, with first/second place as well as third/fourth place being separated by less than 1 % win rate (Table 6). First place was won by tscmoo, a new Zerg bot which played nearly a dozen different strategies, learning which one to choose over time via the file I/O system. In a close second place was ZZZKbot, which implement a 4-pool Zergling rush strategy every game. Despite the relatively simple strategy, most bots did not have proper defense capabilities and lost in very short games. In third place was Overkill, another Zerg bot which had several different strategies including mutalisks and hydralisks, which learned over time as well. In a close fourth place was UAlbertaBot, which played Random and implemented three main rushing strategies – one for each race. An interesting result from this tournament was that despite UAlbertaBot coming fourth place, it finished with a winning rate greater than 50 % versus each other bot. AIUR came in fifth place and was a clear demonstration of how learning over time can dramatically improve results in a tournament, going from 63 % win rate early in the competition to a final win rate of over 73 %.

CIG

An initial attempt to run a StarCraft tournament at the Computational Intelligence in Games conference (CIG 2010) suffered from technical problems. These mainly stemmed from the desire to use evolved, largely untested maps which initially looked interesting but made the submitted bots and the Brood War Terrain Analyzer (BWTA) provided with the BWAPI interface crash so

frequently that it would have been unjustifiable to announce a winner.

CIG 2011. At CIG 2011, the tournament was therefore run with a (secret) selection of maps used in league play, which can be regarded as the most important difference to the AIIDE tournament that employed a known list of maps. The competition was organized by Tobias Mahlmann and Mike Preuss and attracted ten bots. In addition to the ones discussed in previous sections (UAlbertaBot, Skynet, AIUR, Nova, BroodwarBotQ, BTHAI), the set also contained LSAI, Xelnaga, Protoss Beast Jelly, and EvoBot; these are shortly described in the following:

LSAI (Zerg) utilizes a heavily modified BWSAL (https://code.google.com/p/bwsal/) to divide management of the units to different modules that communicate via a centralized information module. It works using a simple reactive strategy to try and survive early-game attacks and macro up to a larger attack force and maintain map control.

Xelnaga (Protoss) is a modification of the AIUR bot that chooses the dark templar opening in order to destroy the enemy base before defenses against invisible units are available.

Protoss Beast Jelly (Protoss) always goes for a 5-gate Zealot rush, supported by an effective harvesting strategy named power-mining (two probes are assigned to every mineral patch, thereby needing 18 probes for 100 % saturation in a normal map, prior to expanding). Gas is not mined as it is not needed for constructing Zealots.

EvoBot (Terran) employs an evolutionary algorithm for obtaining rational unit combinations and influences map techniques for deciding the strategic locations. Note that this bot was submitted in a very early version, with many of its designed features not yet fully ready.

First Round. As the CIG competition games were executed manually due to a lack of available software (the AIIDE program was not yet available at that time), the organizers separated the ten entries into two brackets. In each bracket of five bots, a round-robin tournament was held with ten repetitions per pairing, resulting in 40 games per bot. The five maps chosen for the first round were selected from the pool of well-known league play maps found on the Internet: *(2) MatchPoint 1.3*, *(4) Fighting Spirit 1.3*, *iCCup Destination 1.1*, *iCCup Gaia*, and *iCCup Great Barrier Reef*. Each bot pairing played on every map twice, with switched starting positions.

The two top bots of every bracket qualified for the final round. Table 7 summarizes the results. Note that as BroodwarBotQ and BTHAI have the same number of wins, their direct encounter was

StarCraft Bots and Competitions, Table 7 Results of the first round at CIG 2011, held in two brackets. Qualified for the final round: UAlbertaBot and Skynet (from A) and Xelnaga and BroodwarBotQ (from B, the latter by comparing direct encounters with BTHAI of which 6:4 were won)

Rank	Crashes	Games	Bot	Win %
Bracket A				
A1	0	40	UAlbertaBot	82.5
A2	1	40	Skynet	77.5
A3	2	40	AIUR	60.0
A4	1	40	Nova	20.0
A5	0	40	LSAI	10.0
Bracket B				
B1	12	40	Xelnaga	62.5
B2	3	40	BroodwarBotQ	57.5
B3	0	40	BTHAI	57.5
B4	17	40	Protoss Beast Jelly	42.5
B5	0	40	EvoBot	30.0

evaluated which accounted 6:4 for the BroodwarBotQ. The bots going into the final were thus UAlbertaBot, Skynet (from bracket A) and Xelnaga and BroodwarBotQ (from bracket B). All qualified bots play the Protoss faction. Most bots proved fairly stable; only Xelnaga and Protoss Beast Jelly crashed relatively often (each in more than a quarter of the games). Crashing of course resulted in an instant win for the other bot. In some cases, neither bot was able to finish the other off completely, so that they went into a passive state. Such games were manually ended after around 15 min, and victory was assigned to the bot that had obtained more points as indicated on the end game screen.

Final Round. The final round was played in a similar mode as each of the first round brackets, using another set of five previously unknown maps: *iCCup lost temple 2.4*, *iCCup rush hour 3.1*, *iCCup swordinthemoon 2.1*, *iCCup yellow 1.1*, and *La_Mancha 1.1*. Letting each pairing play on each map twice again with switching starting positions resulted in 30 games per bot. The final results are displayed in Table 8, indicating Skynet as winner and UAlbertaBot as runner-up, being almost equally strong, and the two other bots as clearly inferior. The competition setup, documentation, and results can be found in the 2011 competition web page (http://ls11-www.cs.tu-dortmund.de/rts-competition/StarCraft-cig2011).

CIG 2012. For CIG 2012, the AIIDE tournament software was employed, leading to a total of 4050 games played in 90 rounds of round robin. As six different maps were used, this means that each bot played every other on every map 15 times. As in the AIIDE competition, writing to and reading from a bot specific directory was enabled, however, due to technical reasons, this feature was constrained to the computer (of 6) the game was actually run on. We can therefore assume that this feature was of minor use for the CIG competition. The only other difference to the AIIDE competition was that the used maps were not made available to the competitors in advance.

These maps came in two flavors, namely, three three-player maps: *Athena-II*, *Neo Moon Glaive*, and *Tears of the Moon*, and three six-player maps: *Legacy*, *River of Light*, and *The Huntress 1.1*. We shall note that some bots consistently crashed on one of the originally considered maps which has thus been replaced. This is surprising as all maps are well-known league play maps or have been provided with the StarCraft Brood War distribution itself. Setup, replays, and results for the CIG 2012 competition can be found here (http://ls11-www.cs.tu-dortmund.de/rts-competition/StarCraft-cig2012).

The overall results are displayed in Table 9 and the win rate evolution over time in Fig. 4. These are quite consistent with the results of the AIIDE 2012 competition, so that we can conclude that the best bots are not very dependent on knowing the maps beforehand. However, the bot versus bot win rates as displayed in Fig. 5 show some interesting trends. On the maps with more possible start points, some bots do better than others, namely, SCAIL, Adjutant, Nova, and UAlbertaBot, the latter probably due to its very efficient scouting routine. Some bots however suffer from the increased uncertainty about the enemies' position, namely, Xelnaga and BroodwarBotQ.

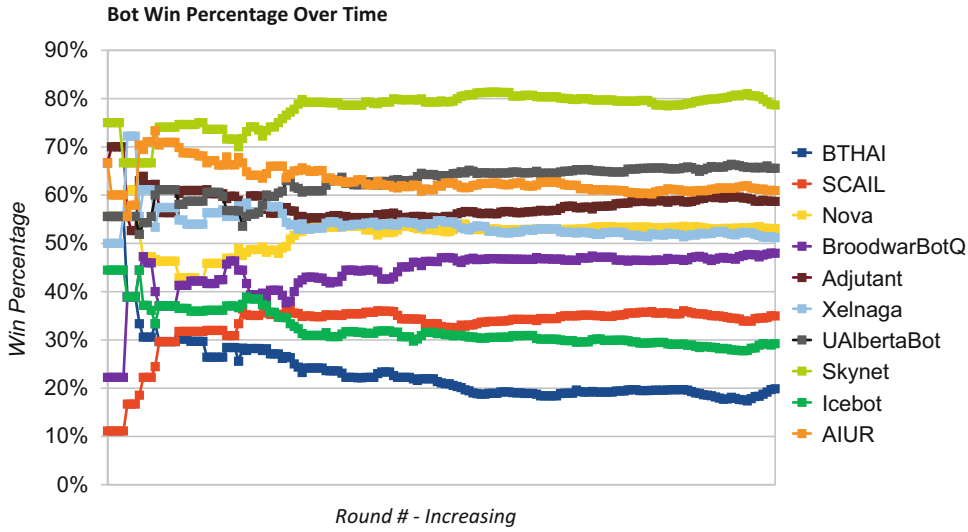
As already observed before in the previously described competitions, there are also bots who consistently beat top ranked bots but have severe problems against lower ranked bots. For example, Xelnaga is especially strong against Skynet on the

StarCraft Bots and Competitions, Table 8 Results of the CIG 2011 competition

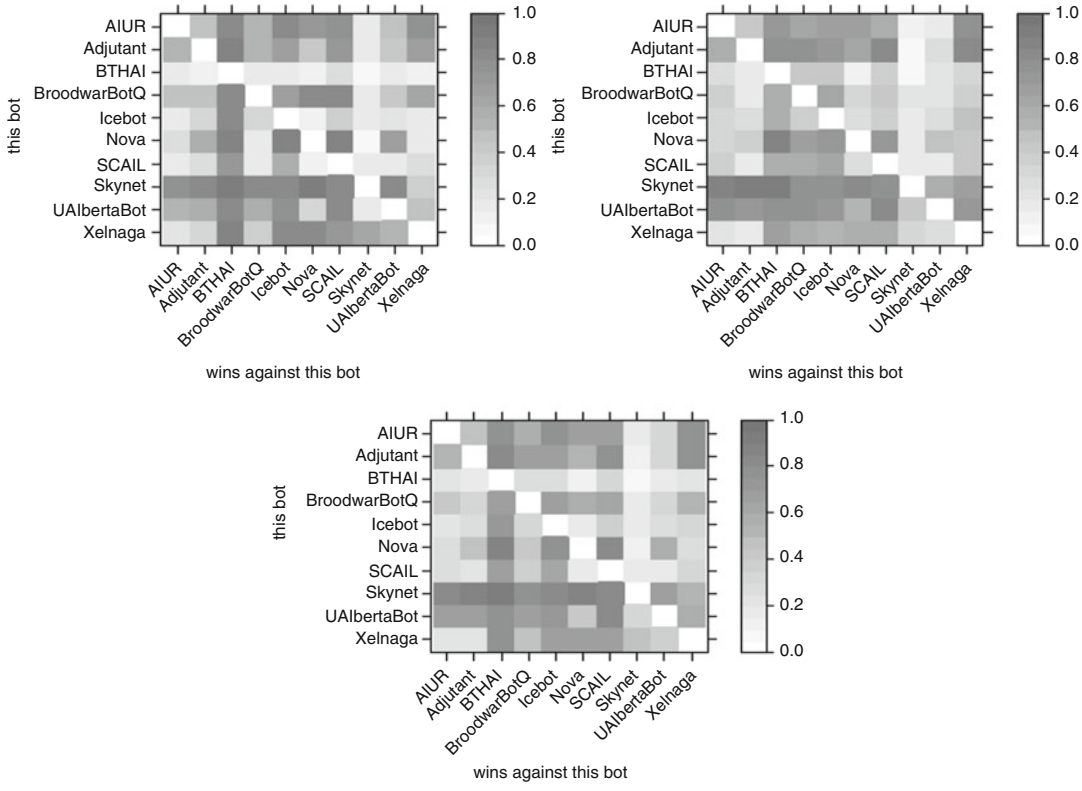
Rank	Crashes	Games	Bot	Win %
1	0	30	Skynet	86.7
2	0	30	UAlbertaBot	73.3
3	3	30	Xelnaga	36.7
4	2	30	BroodwarBotQ	3.3

StarCraft Bots and Competitions, Table 9 Results of the CIG 2012 competition

Rank	Bot	Win %
1	Skynet	78.3
2	UAlbertaBot	65.2
3	AIUR	60.4
4	Adjutant	58.6
5	Nova	52.4



StarCraft Bots and Competitions, Fig. 4 Evolution of the win percentage of each bot participating in the CIG 2012 competition



StarCraft Bots and Competitions, Fig. 5 Win percentages of CIG 2012 competition, from *left* to *right*: three-player maps only, six-player maps only, all maps. Read from line to column, bot in row wins given fraction of games against bot in column. For some bots, we find interesting differences, e.g., Xelnaga gets worse on six-player maps and UAlbertaBot gets better. Only Xelnaga can reliably beat Skynet, but only on three-player maps

three-player maps (about 70 % wins). Reviewing the replays led to the assumption that Xelnaga usually tries to attack Skynet's probes with a dark templar strategy and often succeeds. Nova does very well against the UAlbertaBot, and the replays show that it sometimes succeeds to lure the probes into its own base, where they get killed, leading to severe resource problems. However, we cannot tell how often this happens as this would require to review every single replay between the two bots. Summarizing, most bots seem to have improved, which becomes clear if the nearly unchanged BTHAI bot is taken as a baseline. In 2011, it won more than half of its qualifying games; in 2012 it came out last with around 20 % wins. However, designing a bot in order to beat a top bot (as for Xelnaga with Skynet) leads to a very restricted strategy that often leads to failure if playing against different bots. Note that in the direct encounter between Xelnaga and AIUR, its ancestor, Xelnaga, looses consistently.

Nevertheless, from the observations we made during the tournament, we can draw the conclusion that the available bots are still very constrained. No bot in the competition played the Zerg race, which is surprising as the AIIDE 2010 winner (Overmind) did so. Presumably, implementing a good Zerg strategy is more demanding than implementing one for the Protoss or Terran races. Many bots consistently crashed when playing against a random race built-in bot for testing and also did so when the map size was changed from 128 × 128 to any other. Furthermore, every single bot sometimes failed to finish off an already beaten opponent, such that the game had to be stopped after a previously determined maximum time. It also seems that most of the current bots are not very good at adapting their strategy to the one of their opponent during a game or at least (via the read/write procedure of game information) within a series of games.

CIG 2013. The CIG 2013 competition was once again organized by Mike Preuss (TU Dortmund) and Tobias Mahlmann (ITU Copenhagen), adding Antonio Mora García from the Universidad de Granada as third team member. Whereas the rules and even the participants to this competition were almost identical to the AIIDE 2013 competition setup, several technical changes were made in comparison to 2012 (http://ls11-www.cs.tu-dortmund.de/rts-competition/StarCraft-cig2013). A new competition software was implemented by Tobias but not completely finished in time, so that the read/write function that enables learning between games had to be disabled again. This is probably the most important difference to the AIIDE competition; however, as the result provided in Table 10 shows, the effect is limited. Due to the late availability of the competition software, only 32 rounds of random robin were played, making 896 games altogether and 224 games by each of the eight submitted bots.

StarCraft Bots and Competitions, Table 10 Results of the CIG 2013 competition

Rank	Bot	Win %
1	Skynet	91.1
2	UAlbertaBot	67.4
3	AIUR	54.9
4	Xelnaga	53.6
5	Adjutant	42.4

As the map set has also been changed to the ten standard maps used by the AIIDE competition (without letting the competitors know about this in advance as usual for the CIG competitions), the competitions were otherwise very similar. We presume that disabling the learning was a disadvantage for the UAlbertaBot who won the AIIDE competition and was only runner-up to the Skynet bot here. The third place went to AIUR as in 2012, followed by Xelnaga and Adjutant. A direct comparison to the results of CIG 2012 (Table 9) shows that bot evolution between these two competitions was obviously limited. It also shows that some bots as the UAlbertaBot make good use of online learning, whereas others, as Skynet, do not profit from it that much.

CIG 2014. The CIG 2014 competition was organized by Kyung-Joong Kim, Ho-Chul Cho, and In-Seok Oh of Sejong University. For 2014, the CIG competition used a total of 20 different maps which were unknown to the competitors before the competition started, which was by far the most maps ever used in a StarCraft AI competition and presented a challenge to many of the bots who entered. A total of 4680 games were

StarCraft Bots and Competitions, Table 11 Results of the CIG 2014 competition

Rank	Bot	Win %
1	ICEBot	83.1
2	Ximp	78.1
3	LetaBot	68.5
4	AIUR	66.1
5	UAlbertaBot	60.0

StarCraft Bots and Competitions, Table 12 Results of the CIG 2015 competition

Rank	Bot	Win %
1	ZZZBot	81.03
2	tscmoo-Z	73.59
3	Overkill	62.05
4	LetaBot	61.54
5	Ximp	60.26

played which meant that each bot played each other bot 60 times or three times per map. The CIG 2014 competition was held just a few weeks before the AIIDE 2014 competition and so many of the entrants to the competition were identical, and the results definitely showed this. The top four bots were all the same as the 2014 AIIDE competition with ICEBot coming first, Ximp in second, LetaBot in third, and AIUR in fourth place (Table 11). For descriptions of these bots, please refer to the AIIDE 2014 competition description as none of the top-finishing bots had any significant changes made.

CIG 2015. There were some significant rule changes to the CIG 2015 competition, which was once organized by members from Sejong University. The most significant rule change was that entrants no longer had to be open-source, in an attempt to attract more competitors who may not want to open-source their bots. The second rule change was that a single competitor could submit multiple entries to the competition – which caused some controversy among registrants since this introduces the possibility of collusion between entries. Thankfully no such collusion was detected during the competition. The 2015 competition was also not run quite as long as previous competitions with only 2730 games being played in total, or 30 between each bot pairing, six between each bot on each of the five chosen maps. There were several new Zerg entries to the CIG 2015 competition which ended up finishing in the top three positions, with results very similar to those of the AIIDE 2015 competition. ZZZBot took first place, tscmoo-Z (a Zerg bot written by tscmoo) came second, and Overkill came third (Table 12). For descriptions of these bots and their strategies used, please refer to the AIIDE 2015 competition section as the strategies remained largely unchanged between the CIG and AIIDE competitions.

SSCAIT

The Student StarCraft AI Tournament (http://sscaitournament.com/) (SSCAIT) started in 2011 at Comenius University in Bratislava, Slovakia, and has been well known for being the StarCraft AI competition with the highest number of total participants. Started as a part of a course in artificial intelligence at Comenius University, initial SSCAIT seasons included several dozen student submissions from this course in addition to submissions from across the globe. There are three fundamental differences between SSCAIT and the remaining two conferences:

1. SSCAIT is an online-only event. Unlike AIIDE or CIG, it is not colocated with a scientific conference or any other real-world event.
2. There are two phases of SSCAIT each year: a *competitive* phase, lasting for up to 3 weeks, and a *sandbox* phase which runs for approximately 11 months each year. In other words, SSCAIT is live at all times with only a few short interruptions.
3. All the games are publicly *streamed live* 24 h a day. The stream uses a custom observer script (Mattsson et al. 2015) designed specifically to improve the viewer experience and creates a continuous feedback loop for the participants who can watch their bots play against the others.

SSCAIT 2011. The first SSCAIT tournament was organized by Michal Čertický as part of the

Introduction to Artificial Intelligence course at the Department of Applied Informatics, Comenius University in Bratislava, Slovakia. It was inspired by the media coverage of AIIDE StarCraft AI competition held in 2010, but over the following years, it diverged from AIIDE competition's format significantly.

The first year of SSCAIT hosted 50 participants, all of whom were students of Comenius University at the time. The participants were allowed to select any race and use all the units and technologies in complete 1 versus 1 games of StarCraft. Vast majority of the bots were implemented to execute hard-coded strategies and behavior. Participants were divided into ten groups of five people, and 16 of them advanced into a double-elimination bracket. Final match of the elimination bracket was won by R. Danielis with a 2–1 score against M. Piovarči (both playing as Zerg).

2011 was the only year when the games were not streamed live. However, the replays were published in real time and the games from the elimination bracket were recorded and uploaded to YouTube.

SSCAIT 2012–2015. In 2012, the SSCAIT became a truly international competition with 52 participants from numerous universities including UC Berkeley (USA), University of Alberta (CAN), Washington State University (USA), University of Nantes (FRA), University of Grenoble (FRA), New University of Lisbon (POT), Gdansk University of Technology (POL), Ritsumeikan University (JAP), University of Bielefeld (GER), Sofia University (BUL), Comenius University (SVK), University of Žilina (SVK), and Technical University in Košice (SVK), as well as a number of nonstudent participants.

The format of SSCAIT changed significantly in 2012. The tournament was divided into two phases:

Sandbox phase is played nonstop during the first 11 months of the year. All the games are streamed via a video-streaming service, such as Twitch.tv or Hitbox.tv. The stream is meant to attract new entrants and to help current participants improve their bots before the second phase begins. The participants can watch their bots play against randomly selected other bots. They are allowed to upload new versions of the bots via a web interface at any time during this phase. The sandbox phase has no winners. However, the bots may use this long phase to collect useful data about their opponent's behavior.

Competitive phase is played for up to 3 weeks (depending on the number of participants) at the end of the year. New bot versions cannot be uploaded during this phase and the matches are not scheduled randomly any more. This phase has two divisions with different rules:

- *Student division*: Only the bots created by a single participant, who is currently a student, are considered "student" bots. Other bots are tagged as "mixed division" bots. Each student bot plays a single game against every other bot and collects points for the wins. Three student participants with the highest score are considered winners and receive certificates of achievement (and in years 2012 and 2013 also financial prizes collected via crowdfunding campaigns). Ties are broken using the results of the mutual game and (if necessary) additional games are scheduled. The student division was created so that the students stand a chance of winning the certificates in the presence of more experienced, nonstudent participants and team-created entries.
- *Mixed division*: Eight or sixteen bots with the highest win rate among all the participants (including student and nonstudent entries) are selected for the additional "mixed division" elimination bracket. This part of the tournament is typically recorded with a commentary and uploaded to YouTube, concluding each SSCAIT season since 2012.

The results of SSCAIT seasons 2012–2014 are provided in Tables 13, 14, and 15. At the time of writing this, the SSCAIT 2015 is still in a sandbox phase. 45 bots have registered for the competitive phase so far, including two bots playing as "Random" race. The season will be concluded by an elimination bracket featuring 16 bots in 2015.

StarCraft Bots and Competitions, Table 13 Ranking of the best bots of the SSCAIT 2012 competition (52 participants)

Student division		Mixed division	
Rank	Bot	Rank	Bot
1	Matej Isteník's bot	1	ICEBot
2	Marcin Bartnicki's bot	2	Marcin Bartnicki's bot
3	UAlbertaBot		

StarCraft Bots and Competitions, Table 14 Ranking of the best bots of the SSCAIT 2013 competition (50 participants). The student division winner was determined by means of 1190 round-robin games

Student division		Mixed division	
Rank	Bot	Rank	Bot
1	Ximp	1	Krasi0
2	WOPR	2	ICEBot
3	UAlbertaBot		

StarCraft Bots and Competitions, Table 15 Ranking of the best bots of the SSCAIT 2014 competition (42 participants). The student division winner was determined by means of 861 round-robin games

Student division		Mixed division	
Rank	Bot	Rank	Bot
1	LetaBot	1	LetaBot
2	WOPR	2	Ximp
3	UAlbertaBot		

From a technical perspective, the tournament was run manually in 2011 and by a collection of custom automated scripts in 2012. Since the second half of 2013, SSCAIT has been using the automated tournament managing software developed at the University of Alberta, which was modified to suit the needs of SSCAIT format and technical environment. In contrast to AIIDE and CIG competitions, there is only one game running in SSCAIT at any given time, so that each game can be streamed live (approximately 150 games are played every day). The live stream makes use of a custom-made observer script by Mattsson et al. (2015) which implements a smooth, prioritized camera movement during the game and third-party libraries that allow the game to be displayed in high-definition screen resolution.

Thanks to the tournament managing software, the game rules and I/O procedures have been synchronized with AIIDE and CIG competitions, so the participants are able to submit the same version of their bot to all three of them. In addition to bots written in C++, SSCAIT supports bots using Java interfaces to BWAPI: BWMirror and JNIBWAPI.

Conclusions

Competitions have historically been an important drive in artificial intelligence, with challenge tasks such as *Chess*, *Go*, and autonomous vehicle driving, among others having resulted in many algorithmic and theoretical breakthroughs. For that reason, we believe RTS AI competitions are playing and will continue to play an important role in the field by both motivating new research and also being an incentive to attract new students and researchers to work on some of the key open challenges of RTS AI.

This chapter has provided a summary of the results of the most three most important StarCraft AI competitions, organized during the past 6 years, as well as a summary of the architectures used by some of the bots that regularly participate in these competitions. Moreover, as evidenced by the poor results that the top bots in these competitions achieve when playing against good human players, a significant amount of open questions remain about how to design AI systems that can handle real-time adversarial domains such as StarCraft. Hopefully, these competitions can play an important role in motivating research programs that can ultimately answer these questions.

Cross-References

▶ Computer Go
▶ RTS AI Problems and Techniques

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Statistical Features

▶ Fingerprint Verification Based on Combining Minutiae Extraction and Statistical Features

Steering

▶ Navigation Artificial Intelligence

STEM

▶ STEM Learning Through Video Games

STEM Learning Through Video Games

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Synonyms

STEM; Video games

Definitions

STEM	Science, Technology, Engineering, and Mathematics – a term used to group together these academic disciplines when addressing education policy and curriculum design in schools.
Video Game	A game played by electronically manipulating images produced by a computer program on a display screen of a computer, smartphone, arcade machine, or other devices.
Maslow's Hierarchy of Needs	A theory in psychology proposed by Abraham Maslow to describe the pattern that human motivations generally move through "physiological," "safety," "belonging and love," "esteem," "self-actualization," and "self-transcendence."

Introduction

Those not familiar with the video gaming industry are often quick to assume that video games do not contribute to learning. This fallacy is understandable when we take into consideration the misconceptions that are present. For example, it

is true that a name can lead to stereotyping. Instantly, some people assume that the word "game" in "video game" makes the activity of gaming completely leisure with minimal learning. Unfortunately, those that are inclined to think this way might have missed out on the fun aspect of learning by doing. Additionally, video games take on a bad connotation because many parents blame video games for their child's screen time addiction. Like all good things, video games can be overused and created with content that is not socially acceptable. The same is true for books. As educators we must help inform the public on how the good can outweigh the bad when it comes to video games (How Video Games 2012).

STEM Learning Through Video Games

Video games allow players to learn many different concepts through engaging activities. The laminated cardboard cutouts used in the 1990s classroom were colorful and tactful at the time, but today's students have the Internet and desire to learn in a much more dynamic way. The education and learning process over most recent years has evolved from the classroom having one or two computers with games on CD-ROMS to every student having a Chromebook and access to numerous games on the Internet. Even though this evolution has happened over several years, it seems like the transition happened when some of us were not looking. We step back and wonder how learning occurs by playing Oregon Trail. Laughable is that learning did occur even in the 1980s by playing Oregon Trail, and the games that exist today far exceed anything that was for purchase along the journey to Oregon. This is what brings us to STEM learning. STEM, which stands for Science, Technology, Engineering, and Math, is a topic of interest for school systems and educators across the globe. The STEM movement encourages educators to introduce and focus on the STEM areas to better prepare our students for higher wage jobs requiring skills in the science, technology, engineering, and math professions. The serious need for people to work in these areas has made STEM a priority of focus.

As educators and employers, we have to look at our next generation of STEM learners to understand how they learn and why they learn. Careful consideration must be given to the resources that the next generation of STEM professionals have access to and are willing to use. Because video games are a part of most K-12 learning environment in the classroom, it makes sense that video games be used as a tool to teach STEM. Students are comfortable with playing video games and are accustomed to the challenge of making it to the next level in a video game.

How video games teach STEM really is not a secret or mystery. In actuality it is easier than taking a student to a library and giving them a book to read. Video games accessible through the Internet allow educators and employers to meet students where they already are – online gaming. The skills needed to play a video game are instilled in children from a young age, eliminating training and apprehensiveness. Students get engaged in video games that create a learning environment that is fun, challenging, and comfortable. STEM learning through video games might not allow students to reach the top of Maslow's hierarchy of needs at first, but the safety, belonging, and esteem can be achieved. To meet the demand for STEM professionals in the workforce, video games will be key to exposing larger amounts of students to the possibilities of a career in STEM much quicker than reading a book or taking a high school or college course. A young girl can feel safe to try out coding, by playing a video game on a website like code.org. A college student not confident in their math skills can become better prepared for calculus by taking game-based calculus course like the one at Texas A&M (Zarling 2018). Students ages 8–15 can play in Whyville and learn the science behind saving a coral reef (Rik on Mon 2009). In 2011, gamers playing a puzzle game that simulated protein folding found the solution to an enzyme in 3 weeks that stumped scientists for 14 years (Coren 2011).

In summary, the rationale behind teaching STEM through video games is simplistically

complicated. We have the widely accepted technology readily available for use. Numerous video games all designed with STEM in mind exist for students to take advantage of. Educators, governments, and employers alike are working together to create STEM learning. The next complex challenge is to make sure we are using these tools to help our students find a pathway from the video game to higher education to the workforce.

Cross-References

▶ STEM
▶ Video Games

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Stereo

▶ Virtual Reality Stereo Post-Conversion After Effects Workflow

Stereoscopic

▶ Virtual Reality Stereo Post-Conversion After Effects Workflow

Stereoscopy

▶ Spatial Perception in Virtual Environments

Storytelling

▶ Game Writer's Dilemma: Context vs. Story
▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
▶ Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation

Storytelling in Virtual Reality

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Synonyms

Immersive storytelling

Definition

Storytelling in virtual reality (VR) is the use of a narrative form to structure an immersive experience in a virtual environment as a means to engage the audience in a more sustained, active, and meaningful way beyond the initial captivation afforded by technological novelty and surround spectacle. It recruits storytelling's unique abilities to combine tangible and intangible information, and to capture context and tacit knowledge, in order to amplify presence and enhance the digital simulation's impact.

Introduction

Storytelling in VR is increasingly being employed in various fields, including journalism, the healthcare sector, cultural heritage and museology, education and training, advertising, and gaming industries (Bosworth and Sarah 2019; Papagiannakis et al. 2018). While frequently utilized in a documentary, promotional, or modeling capacity (e.g., data visualization), storytelling in VR is particularly effective when compared to conventional media in rousing users' empathy and willingness to engage with unfamiliar, challenging, or fictional worlds (Bosworth and Sarah 2019; Bucher 2018), owing to the medium's unprecedented access and embodiment potential.

In contrast to traditional oral and written storytelling primarily aimed at transmission (i.e., education, cultural preservation, and/or the instilling of moral values by means of entertainment), storytelling in VR is further oriented towards generating user agency through interaction (Riggs 2019; Arnold 2008), embodiment (Matamala-Gomez 2019), presence (Sanchez-Vives and Slater 2005), and simulation (Bertrand et al. 2019). Insofar as interactive modalities conflict with classical, pre-scripted, authored storytelling paradigms (Pausch et al. 1996), giving rise to a narrative paradox (Riggs 2019), storytelling in VR remains a nascent form that still requires further experimentation with a view to developing new storytelling models and concepts adequately tailored to the medium.

Programming Narrative Structures in VR

Programming storytelling in VR currently assumes a variety of dramatic structures ranging from predetermined linear arcs to branching narratives with diverging plotlines and/or alternative endings (Pausch et al. 1996), to highly complex rhizomatic maps of events (i.e., emergent rule-based models) that trigger one another based on user interaction (Riggs 2019; Spierling 2007) – though it has been suggested that the decisive success of the latter may yet require considerable advances at the intersection of AI and narratology (Bucher 2018). Beyond anchored 360-degree footage providing static immersive experiences, interactive functionality and navigation are generally created through game engines, combining 3D world–building capabilities with a user interface (Riggs 2019).

Irrespective of their pre-scripted or emergent nature, narrative structures in VR generally rely on classical Aristotelean elements of storytelling: archetypal characters motivated by internal and external goals with universal resonance driving a plot (series of events) constructed around conflict and resolution (Riggs 2019; Bucher 2018). They are invariably situated in a specific cultural context (Quesenbery and Brooks 2010) designed to reinforce narrative meaning and coherence by means of environmental storytelling techniques (e.g., color, lighting, and costume) to ensure a purposeful and motivated mise-en-scene (Bucher 2018; Arnold 2008). A number of VR experiences continue to be crafted around the traditional three-act structure, as well as Joseph Campbell's conception of the hero's journey (Riggs 2019; Bucher 2018). Other external sources of reference for storytelling in VR include: open-ended literary genres such as create-your-own-adventure books, immersive theater, experimental art installations, and theme park attractions (Riggs 2019; Bucher 2018; Pausch et al. 1996).

Audience Engagement

One of the main advantages of using storytelling in VR is that notwithstanding individual subjective reception owing to different cultural backgrounds, values, beliefs, and memories, simple narrative cues can provide fairly consistent user interpretations (Jerald 2016). Additionally, VR's prime affordances, i.e., presence (the feeling of "being there" in the virtual environment) and embodiment (e.g., the sense of body-ownership for a virtual body, even if radically different from one's own), result in mental constructions composed of perceptions and ideas that are different in kind from other types of knowledge, and were never before available with previous forms of interactive storytelling.

In contrast to traditional storytelling techniques, VR's shift from a frame (i.e., screen or theatrical fourth wall) to an environment requires different narrative cues and prompts, such as spatialized auditory effects (Bosworth and Sarah 2019), in order to guide the users' focus and direct their shifting center of attention within the immersive experience (Pausch et al. 1996). Rhizomatic storytelling structures further necessitate the introduction of pre-scripted plot points and bottlenecks to ensure that all emergent narratives are coherent and comprehensive, unfolding in a logical order so as to provide a dynamic but still unified experience (i.e., without plot holes, dissonance, or confusion) that is responsive and personalized to individual users (Riggs 2019; Bucher 2018). A coherent sequence lacking adequate well-timed dramatic tension will fail to sustain attention and interest, while an incoherent or nonsensical narrative arc (e.g., conflict without resolution) will lead to frustration, boredom, and disengagement (Riggs 2019).

As with any VR experience, sustained credibility is key and poses additional conditions distinct to narrative integrity. Beyond the believability and relatability of the environment, objects, characters, and avatars (Arnold 2008; Pausch et al. 1996), effective interactive storytelling in VR further requires that experiences in the virtual world correspond to social expectations in order to avoid narrative limbo (Riggs 2019) and dissociative responses. Added consideration to scene transition is equally vital in maintaining immersion, given contemporary audiences' media-conditioned anticipation of continuity in real-time, even daily life, experiences (Bucher 2018). Narrative length and pace should also be adjusted to factor in exploration time, cognitive overload (Bosworth and Sarah 2019), and various audiences' tolerance threshold for the VR experience (Bucher 2018; Pausch et al. 1996).

Narrative Paradox and User Agency

Storytelling in VR presents a narrative paradox between predetermined structure and emergent interaction (Riggs 2019): viz. between explicit authoring and implicit creation (Spierling 2007). More scripted and authored narratives can stifle user interaction, while extensive agency can flatten, even eliminate, dramatic structure (Riggs 2019). If the absence of a frame suggests the need for new types of story-worlds built around dynamic emergent narratives evolving in response to user interaction (Riggs 2019), human's inbuilt neural propensity towards pattern processing may still advantage traditional narratives over nonlinear stories (Bucher 2018). Ultimately, successful storytelling in VR requires a balance between dramatic structure and user agency (Pausch et al. 1996).

Depending on the extent of scriptedness and interactivity, user engagement can range from static immersion: whereby the user might have a stationary position in a fixed narrative designed to elicit an increased sense of empathy vis-a-vis an unfamiliar situation; to extensive interactive, even creative control: where the user is given broad agency to determine the storyline based on personal goals and motivations (Bosworth and Sarah 2019; Riggs 2019; Bucher 2018). These different kinds of engagement programmed through different points of view, positions, and functionalities amount to different types of user agencies with diverging effects. Users might be granted protagonist status with God-like influence over the simulated environment (Riggs 2019) amenable to being manipulated at will – which can raise ethical issues related to playing out personal fantasies (Bucher 2018); or assigned the role of a supporting character or invisible observer (Bosworth and Sarah 2019; Bucher 2018), akin to an ethnographer or critic, conducive to a more critical, judgment-based mode of engagement – that is, however, circumscribed in its impact on the virtual environment.

In either respect, aside from interactive features, active storytelling approaches that leave deliberate gaps in thematic or narrative detail to be completed by the user present another effective means of compelling audience involvement through imaginative projection (Bucher 2018). Such parcity in detail can effectively serve to condense information and simultaneously elicit personal investment and connection to content

through mental imagery (Bertrand et al. 2019), sparking understanding and innovation, and even amounting to ownership and coauthorship (Quesenbery and Brooks 2010).

Conclusion

Given that narrative structures are fine tuned to human cognitive patterns of attention and problem-solving, storytelling in VR can contribute to greater presence and agency via embodiment and interaction, conducive to more individually meaningful experiences in simulated environments. It is an efficient means of structuring user engagement in virtual worlds for audiences that are increasingly becoming accustomed to nonhierarchical interaction, and eager for momentous and immediate experiences to offset image saturation (Bucher 2018).

Cross-References

- Gamification and Serious Games
- Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
- Narrative Design
- Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation

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Strategies for Design and Development of Serious Games: Indian Perspective

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Synonyms

Game development; Game strategies; Indian perspective; Purposeful game; Serious games

Definition

Serious games are those games in which the primary objective is not fun or amusement, but to learn or develop skills. Their goals may be one of many: training defensive teams in emergency situations, training for a marketing team, teaching science, or rehearsing a language. These games have the potential to create empathy for particular topics, spread awareness users about important issues, and solve problems with evolving behavior.

Introduction

Great Philosopher Plato quoted "Life must be lived as a game". Play is inherent in the human psyche. Translations of human activities into play for recreation have taken place since the evolution of mankind. From the Stone Age to Mesopotamia to Mohenjo-Daro, across civilizations, human artifacts and behavior were reflected in a style of playing that constituted a game. Games generally obey those laws that are conditioned by society. A game requires the human mind to elicit fun using its cognitive reasoning. The human mind appears to make games based on its emotions.

Game can be described as a physical or mental contest following particular rules and having players with the target of amusement or rewards (Williams 2006). Various types of fun games, such as board games or video games, follow the direction of wining or loss. Sometimes the players' minds get so engaged and involved that they get addicted to it. In today's context, games are no longer just for recreation purposes, they have also begun to be used as tools to serve behavioral changes among people. Such games have some meaningful purposes apart from fun. So, evolution has happened and given rise to games with purpose. These were named as "Serious Games" wherein players gain an understanding of real-world issues through play.

Origin of Serious Games

The origins of serious games are quite old. In 1970, Clark C. Abt coined the word "serious games" (Abt 1970) in his book and the term was later popularized by Ben Sawyer in 2002. However, considering the rich history of purposive play, these are traceable to Plato's work. In a way, serious games is a contemporary manifestation of centuries-old theories and practices. "Chaturgana," that historians claim to be the precursor of chess, was the first game to explicitly apply a militaristic metaphor to a board game developed in India in the seventh century (Shenk 2011). Chess, although it might be popularly regarded as an entertainment game, has the underlying element of strategic skill training and is therefore a form of serious games.

However, these are traceable to Plato's work in view of the rich history of purposeful play. Serious games is somehow a contemporary manifestation of theories and practices that go back centuries. "Chaturgana" was the first game to explicitly apply a militaristic metaphor to an Indian board game developed in the seventh century (Shenk 2011). Chess is a strategic training component, although it can be popularly considered as an entertainment game, and therefore constitutes a form of serious games.

Accepting this as a beginning stage, we would then be able to follow this aggressive use of games to more unmistakable advanced serious games, for example, America's Army, Phil Wilkinson discovered in his research that there are examples of pre-digital games intended to create social change and the legislative use of games for serious purposes, similar to the recorded use of games in instructive and military settings. Similarly, the Landlord's Game, which was supposed to be the precursor to Monopoly when it was founded in 1902, was intended to show the risks of capitalist approaches to land taxes and rental property (Alvarez and Djaouti 2011). Concepts dominant in the debate on contemporary serious games are also concepts reapplied from historical origins.

Various Applications

Serious games are persuasive games that enable players to obtain through play an experiential understanding of real-world issues. Numerous in this developing class of games tackle social causes. Serious games in real-world scenarios are often intended to "improve" players' knowledge, awareness, or skills. They may seem like simulations of infotainment, training, therapy, or even propaganda. These games are generally used in education, training, health, public policy, defense, and strategic communication.

Serious games were adopted in early psychoanalytical methodologies. In fact, they can be traced back to Sigmund Freud as the first case of play in a therapeutic setting. He suggested to the parent that the child watch play at home in a way that provides an insight into their mindset when treating a young phobia affected boy (Roos and Roos 2006). The use of play by Anna Freud as a means of developing child therapy relations was similar to this approach created by Freud and extended further by Madeleine Klein. Perhaps Carl Rogers' humanistic psychologist's work in the field of play therapy is of the utmost importance today for the therapeutic use of serious games (Rogers and Dorfman 1951).

Popularization

Apparently, the spectrum of serious gaming applications in the healthcare sector is very diverse. In the same way, there is a range of different players in this field, including hospitals, clinics, private practitioners, consultants, staff trainers, government, businesses, and other organizations and individual users. The popularization of gaming coincided with the technological transition from analog to digital gaming. Rosemary Garris, Robert Ahlers, and James Driskell created a thorough analysis of preexisting research into serious games to strengthen its application in education in 2002. Garris et al. (2002) have worked with the United States Section of the Naval Air Warfare Center, showing the military's continued role to advance research in serious games. They also looked at the work of existing researchers with a view to developing an illustrative and formal model for serious educational games (Garris et al. 2002). Finally, they illustrated their work as an educational game.

Serious games can be enhanced to a wide range of uses, e.g., military, governmental, educational, commercial, publicity, healthcare, etc. Serious gaming encompasses games used for purposes other than sheer entertainment, such as e-learning, game-oriented learning, and game-based interactive learning. These games allow students to experience scenarios that would otherwise be impossible due to security concerns, financial constraints, time constraints, and so on. Serious games incorporate cognitive theory with human behavioral psychology, game design, and are designed to improve the student's understanding of the intended purpose (see Fig. 1). Serious games cover all facets of education and learning well beyond teaching and rote memorization.

The Army Battlezone, designed by Atari in 1980, was the first "serious game." However, the American Army was one of the most famous and perhaps leading examples of serious games in 2002. The game highlights realism, and all weapons and cars, for example, are exact virtual replicas of the real thing. This game became very popular, as a community of four million registered players was downloaded 17,000 times in the autumn of 2004, and the number of players increased by 100,000 per month (Michael and Chen 2006) With an investment of 16 million dollars in the U.S. Army, the game has been a success to help the Army recruit 15% of its recruitment costs (Grossman 2005; Michael and Chen 2006). The game also helped to strategies and was used by active soldiers to prepare for missions with subsequent modifications and extensions (Michael and Chen 2006). Another advantage of this particular game (for the Army) is that its target audience considered it to be an important source of military information and knowledge. It is estimated that 30% of Americans between 16 and 24 years say that they have learned something from this game about the army (Grossman 2005).

Strategies for Design and Development of Serious Games: Indian Perspective,
Fig. 1 Correlations of elements of serious games

Categories of Serious Games

In the same way, serious government policy games will include different types of tasks and circumstances, such as dealing with terrorist threats, outbreaks of disease, biohazards, health policy issues, urban planning, traffic management, firefighting, budget balancing, ethical training, defensive driving, and other crisis management. In order to simulate scenarios that are too risky, difficult, or costly to handle, that are hazardous and train havoc, most of the simulations will be made for different types of emergencies, for example, firemen, policemen, or medical personnel. Similarly, serious education games can advance the improvement of a scope of abilities: strategic thinking, planning, communication, teamwork, community decision-making, cooperation and negotiation (Kirriemuir and McFarlane 2004). With the renewed interest in serious games, game creators have shifted from 'mugging and repeating' learning paradigms to situational and experiential learning where people are active in making tangible objects in the real world.

There are majorly five categories of serious games classified by Alvarez and Michaud (2008) as represented in Fig. 2. The games that raise awareness of issues help to train motor functions, develop social skills, develop ability to respond to sudden onset crises, and improve imagination. It helps grow entrepreneurial potential, build human capital and workforce, and enhance organizational management. Today's corporate training market is a large industry in which serious games are widely used. In the 1990s, computer-assisted training was introduced to digital PC companies, first with CD-ROMs, and later on the Internet. While computer-aided training allowed firms to reduce training personnel, special equipment, places, and so on costs for training, there were not significant differences in learning and interaction compared with previous training courses (Michael and Chen 2006). As new technology and media are available, they are adopted for corporate training and for several reasons. Interest in major games and simulations is now growing. The number of employees familiar with video games is increasing and their interest in

Strategies for Design and Development of Serious Games: Indian Perspective, Fig. 2 Categories of serious games

interactive serious games is quickly and effectively captured.

Corporate serious games may include a variety of subjects, some common to various corporations, while others are unique to the needs of a company itself. These games address skills that companies need to train their workers in, such as interpersonal skills like teamwork, job-specific skills of software/hardware knowledge – organizational skills including managing resources and energy, communication skills, and planning skills.

Serious games provide a paradigm shift in training, changing the position of the trainee from passive to active, from simply supplying materials to facilitating the trainer's role. These games allow the learner to get feedback on behavioral outcomes using assessment methodologies that can be both quantitative and qualitative. Serious games applications are becoming more popular and there are various kinds available nowadays. Healthcare is the application field of serious games that will expand mostly in the coming years according to Ben Sawyer, co-founder of the Serious Games Initiative. Dance Dance Revolution game (DeMaria 2006) may serve as an example of serious games and input tools that encourage healthy behavior, such as a stationary bike. By incorporating physical activities to the entertaining elements of video games, or vice versa, physical activities are more appealing.

Indian Folklore and Serious Games

Recently in India, many have explored the domain of serious games to enhance efficiency corporate workflow and trainings and been developed independently. Like, "Acting Kindly" is a kind of serious games developed in India to make kindness fun. It is a perfect game for parents to play with their children, organizations to encourage team building, or for friends to have a fun time while making the world a better place. It encourages people playing can run along doing acts of kindness in public.

India is currently experiencing a transitional period as it embarks on a grand journey towards growth. This is a very interesting and probably the most important phase the country is witnessing. Modern ideas are being challenged today by old ideas and institutions. Innovative solutions are being provided to both old and new issues. However, there are few major issues and challenges which need to be dealt effectively for significant progress.

Content, creativity and common sense can be strategically combined to design novel game concepts that make societal impact, while being fun to play. Games can be designed to address digital inclusion, women safety, traffic behaviors, clean India – things that matter in day-to-day civic life in the Indian context (see Fig. 3).

Strategies for Design and Development of Serious Games: Indian Perspective, Fig. 3 "Rani Laxmi Bai" India's warrior queen from history could be used in RPG (role-playing game) where she would be guiding young girls for self-defense

Jataka Tales to Serious Games

The gamut of serious games could be explored in different games with purposeful meanings. Game designers could connect the dots and find solutions to current issues in India, by creating strong, original narrative games inspired by India's own indigenous stories and culture. One could revisit native subjects and see things from different perspectives, to come up with solutions to serious games that are needed to push the boundaries. One could explore Indigenous Tales (Indian Folk Tales) and apply to solve the present problems plaguing our country.

India has a huge collection of courageous ballads and epic verses safeguarded in oral convention, both in Sanskrit and the different vernacular dialects of India. There is an enormous potential in the digital serious game arena to create games that are influenced by the culture and folk tales of India. Panchatantra, for example, offers human life moral values. It is estimated that The Hitopadesa is at least many centuries old. Originally written in Sanskrit, animals were often used to represent values about how to behave in everyday life. The Jataka tales are a voluminous body of Indian native literature about Gautama Buddha's previous births. These are the stories that tell, in both human and animal form, about Buddha's previous lives (Panda 2013).

Conclusion and Future Scopes

Indigenous stories and Indian history have tremendous potential to be used in dealing with issues prevalent in India. For instance, crime like against women such as rape could be highlighted by RPG (Role- Playing Game) wherein the protagonist could be Rani Laxmi Bai (the historic brave lady figure). She could be a warrior against such crimes and teach different techniques of self-defense to young girls. The narration could be inspired by Rani Laxmi Bai in the present urban scenario (Deshpande 2008).

Likewise, to create awareness on the other socially relevant topics in India, like protection of the girl child, unplanned pregnancy, abortion of female fetus, etc., serious games could be developed having strong narration which would be truly "Indian." Serious games for tackling the present challenges in India such as water scarcity, pollution, public transportation, road safety, digital banking, etc. could have a back story inspired from Indian cultural gems like Jataka tales or Panchatantra. Such Indian heritage has strong moral values which are still very relevant in the present scenario. The solution could be built into the progression of the game. Indigenous Indian narrative could make the whole experience interesting. The purpose of such games could range from providing learning, creating awareness, solving problems to changing behaviors. Businesses, governments, NGOs, and educational

institutions are considering serious games to promote their commercial either social causes or to facilitate academic learning. The purpose of such serious games may range from providing instruction, generating knowledge, solving problems, and helping to change attitudes and behavior for betterment of mankind. These games can be used by government, educational institutes, corporates, NGO, etc. for several kinds of awareness campaigns in the public domain. Serious games are perceived not only as an entertainment source but also as an effective pedagogical tool (Shaffer et al. 2005). Simulation and other games are very useful in allowing user to experience real-world problems and improving their understanding.

As a future scope, apparent usability testing of serious games with players may be useful to investigate along with the visual aesthetic might have same effects performance (Shirole et al. 2018). Human factors/ergonomics research aids in the development of appropriate serious game attributes. These users' requirements include emotional attachment to serious games, cultural perceptions, and social value systems, all of which will provide valuable insights for game developers (Chowdhury 2020; Chowdhury et al. 2014; Goyal and Chowdhury 2021).

Further, serious games can also be combined with hypnotic voice user interfaces to enhance the player's engagement in future. Hypnosis and hypnotherapy are fascinating forms of interaction between the subject and the hypnotist, with very subtle suggestions (Ramadas and Chowdhury 2020) introduced in their research article a new type of discrete human-machine interaction called hypnotic computer interfaces. The triggers can be verbal, nonverbal (such as guttural sounds, gestures, and facial expressions), intraverbal (a combination of two or more words), or extraverbal (a combination of verbal and nonverbal). The input can come from humans and the feedback can come from the machine, or vice versa in this type of interaction.

Serious games have the potential to act as alchemists, assisting in the transformation of society. Moral lessons in folk tales assist young people in developing as healthy, mature, and responsible members of society (Dixit et al. 2017). Inspiring morals from our country's indigenous folk tales could be strategically used to promote values, thereby improving human life and society as a whole.

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Strategy Game

▶ World of Tanks, MMO Strategy Freemium Game

Stress Reduction, Relaxation, and Meditative States Using Psychophysiological Measurements Based on Biofeedback Systems via HRV and EEG

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Synonyms

Psychophysiological coherence and cognition of inner peace and harmony

Definitions

Electroencephalography, or **EEG**, is an electrophysiological monitoring device comprised of multiple electrodes (small, flat, metal discs with thin wires) placed on the scalp that send signals to a computer in order to noninvasively measure and record electrical activity on the scalp. **EEG** can be used in cognitive research or to diagnose conditions such as epilepsy and sleep disorders.

Heart rate variability (HRV) is a measure of the patterns prescribed by interbeat intervals of time and the functioning of the heart. **HRV** has been described as a psychophysiological biomarker to assess coherent or stressful states associated with respiration, cognition, and emotions (McCraty et al. 2009).

Psychophysiological coherence has been widely described as a state conducive to optimal cognitive performance and improved health (McCraty et al. 2009) that has also been associated to inner balance, peace, and harmony (Davis et al. 2018).

Biofeedback systems are computerized devices that provide information about the activity of physiological measures, such as heart rate variability, in order to learn how to modulate at will specific body functions to improve energy management, health, self-mastery, and general well-being. Biofeedback systems may include HRV, EEG, ECG, EMG, and respiration machines, among others.

Brain or heart computer interface refers to cybernetic systems that allow data acquisition from sensors or electrodes, which monitor brain dynamics via EEG or cardiac activity via HRV, with the possibility of online processing and data storage capacity.

Multiuser computer games are games that allow audiovisual and text exchange via personal computers, laptops, tablets, or smartphones, which facilitate online interaction between different users in different locations.

Introduction

Since ancient times humans have lived in a struggle between the fulfillment of survival needs and the achievement of inner peace. Many ancient traditions provide a body of wisdom with tools and practices to achieve such inner states. However, for the majority of people “making a living”

in the modern world, long meditation retreats or spiritual quests become a luxury that is difficult to attain. Fortunately, modern technology when combined with ancient wisdom, mainly breathing techniques, can support us to move closer toward the ideal of inner peace with very good results. Recently many users of biofeedback systems have incorporated these tools to accelerate their learning process in achieving peaceful cognitive states associated with low stress levels and cognitive clarity, with their associated mental, emotional, and physical benefits. There are different types of biofeedback systems available; however, here we focus on EEG and HRV only.

The purpose of this entry is mainly informative and emphasizes the benefits of using biofeedback systems in order to reduce and manage stress as well as to harness positive emotions, optimal cognitive performance, general well-being, and inner peace. Throughout the entry the reader is guided and referred to what the authors consider a condensed, solid body of literature to support in deepening his or her understanding on the subject. Perhaps one of the main contributions of the entry is in highlighting the need to synthesize a body of knowledge that brings together the role of brain, heart, and respiration interactions in mediating cognition associated to inner states of peace and harmony. The authors would be glad if the reader felt encouraged and inspired to conduct more research in this promising area as well as derive benefit from the use of these kinds of biofeedback systems.

Modern biofeedback systems combine the analysis of EEG data together with a very coherent, informative, and aesthetic display and are able to provide an almost instant reading, as well as keep records of the different sessions of relaxation or meditation, for example, and their associated brain dynamics. This serves the user in learning how to modulate brain states at will, by making sense of the graphical output in relationship to the subjective knowledge of one's self and one's cognitive states. With practice and attention, the user can induce at will alpha (~10 Hz) states in certain regions of the brain, and that may serve as a biomarker for, let's say, a relaxed state (Davis et al. 2017; Davis and Kozma 2018a). Such a tool can also be enhanced by a monitor of HRV, which according to many studies (McCraty and Tomasino 2004; McCraty et al. 2001, 2006; Davis et al. 2018) serves as a good indicator for psychophysiological coherence and relaxed and harmonious inner states. Most of the currently widely available biofeedback systems provide one or the other tool; however, it is expected that in the near future, biofeedback systems will integrate heart and brain measures together with others like respiration rhythms and hormonal release measures, for example.

More importantly, all these technologies, we conjecture, could be integrated to a new generation of multiuser computer games, which will challenge and support every user in virtual interactions to acquire cognitive and psychophysiological coherence skills. These computer games could also be integrated as part of the education process in acquiring social skills and the knowledge to achieve general well-being. It is important to note that these computer games could also be developed in applications for smartphones and other devices with intelligent advisors that suggest a set of activities or missions to be accomplished and monitored in real life, for example, the new application by the name "Mission Me" (Apple Inc. 2018).

Biofeedback Systems, a Means to Relaxation, Meditation, and Stress Reduction

Cognition and Brain, Heart, and Respiration Interactions

Understanding the complexities associated with the generation of peaceful inner states is a prerequisite to building reliable biofeedback systems. For example, when the synchronization and desynchronization between different oscillatory systems in the body are observed via multiple biomarker measures, we are challenged to systemically study the dynamics of the heart, the brain, and the respiratory system to name a few and, in doing so, unravel their coupling properties in

describing different cognitive states usually associated with different emotional expressions as shown in recent studies (Heck et al. 2017). It is common knowledge that emotional and mental states that are commonly associated with an "aching heart" and a "confused mind," caused by marital breakdown, for example, come together with very different bodily sensations than the experience of "nirvana" or "joy" that people experience in meditative states. Therefore, it becomes relevant to know how the heart, the brain, and the hormonal system act as coupled oscillators and then use this knowledge to learn how to modulate their dynamics at will, via the respiratory system, with rhythmic breathing techniques that may facilitate a transition from an "aching heart" into a "joyful" one and from a "confused mind" to a "clear mind" state.

The Engineering of Biofeedback Systems for Well-Being

The design of a biofeedback system is a work of engineering that may require input from many different areas of knowledge like science, art, philosophy and ancient wisdom, and most certainly the development of mathematical methodologies that involve both linear and nonlinear systems and that could possibly describe brain dynamics, for example, as a consequence of intentional action and values-based decision-making, leading to cognitive states which are associated with inner peace and harmony, involving the abovementioned oscillatory systems (Baars 2013; Freeman et al. 2000; Buzsáki 2006; Davis 2009; Schwartz et al. 2005; Kasamatsu and Hirai 1966; Austin 1999; Childre and McCraty 2001; McCraty and Tomasino 2004).

This would mean that a well-designed biofeedback system should allow the user a cybernetic interaction (human-machine interaction) with the goal and intention to achieve relaxation and inner peace by exploring different choices and making decisions that are valuable and meaningful for the user, for example, meditating before an exam or important meeting in order to improve cognitive clarity and emotional stability (McCraty 2002, 2017; McCraty and Tomasino 2004).

Brain and Heart Dynamics, Cognition, Consciousness, and General Well-Being

Some authors have developed theories and methodologies to study cognition that are intended to improve on the understanding of the brain in a holistic or systemic way, based on brain field dynamics (Kozma et al. 2012; Davis and Kozma 2012, 2013; Kozma and Freeman 2002; Pribram 2013). These methodologies based on Freeman's neurodynamics and Pribram's view of the brain are very relevant to the study of mind and consciousness, as manifested in nonlinear brain dynamics that involve large cortical regions intended to uncover how the brain allows for perception of reality and the emergence of knowledge and meaning in relation to the higher faculties of the mind (Del Cul et al. 2007; Seth et al. 2008). The reader needs to note that the mind and its workings are intimately related to the willful generation of relaxed, less stressful, and ideally peaceful states and that these kinds of theories and methodologies are instrumental in designing algorithms to analyze brain data, which ultimately can be embedded in robust biofeedback systems that allow for cognitive inner state exploration via monitoring brain activity (Davis and Kozma 2014, 2018a).

Similar theories and methodologies have also been developed for the analysis of heart rate variability signals based on a thorough understanding of the complex interaction between the two branches of the autonomic nervous system, the respiratory system, and the heart. These methodologies have also contributed to the design of biofeedback systems that support the learning process of modulating one's cognitive and emotional states (McCraty et al. 2006).

The Art of Electroencephalography (EEG) as a Qualitative Biomarker

Perception of reality is modulated by the interaction of the environment and our human body. Each time we receive sensory input or generate internal signals associated to hope for a desired goal, for example, our brain, which is a very complex system, interacts and communicates

continuously with different systems in the body, like the nervous, cardiovascular, and respiratory systems, to name a few. The body, when taken as a whole, is better comprehended in its functioning, and it is easy to realize that changes which manifest in one bodily system will affect other organs, members, or systems of the body. Intentional action requires the brain to create knowledge and meaning and that in turn provides a means for evaluating, coordinating, and controlling human behavior. Learning about our reactions and thought patterns and how to keep and nurture the constructive ones, while addressing properly the destructive and negative ones, requires self-vigilance and mastery. Meditation has been proposed as a practice to achieve such self-mastery, and Sarah Lazar among others has conducted studies in this area. The reader is directed to a comprehensive list of Lazar's publications (Lazar 2018).

Disturbances associated with stress that are received from diverse sensory input have been shown to manifest in a variety of frequency bands in brain dynamics (Freeman and Quiroga 2013; Freeman et al. 2003), while peaceful cognitive states, when self-induced via meditation, have been observed predominantly in the mid-range of brain frequencies known as the alpha band (Freeman et al. 2000; Buzsáki 2006; Davis 2009; Schwartz et al. 2005; Kasamatsu and Hirai 1966; Austin 1999). In order to benefit from the information that our brains can provide, we need tools like biofeedback systems that are integrated to EEG data acquisition and the analyses of these EEG signals.

Modern technology has allowed for EEG-based biofeedback systems that can incorporate a graphical display module of brain signals or a movie of spatiotemporal brain dynamics (Davis et al. 2015a) that help the practitioner or user to engage in visualizing brain patterns, either intermittently during or post meditation, in order to learn to change the pattern that is visualized, by changing breathing patterns or attention, for example, until the desired cognitive states are achieved. It is similar to an explorer seeking for a path to the river in the forest; once it is found, traces are left with the proper markers. In our case these markers are movies or displays of brain dynamics (Davis and Kozma 2018). A practitioner or user could learn the differences between various cognitive modalities and their associated brain dynamics and subjective experience, such as (a) closed eyes; (b) open eyes; (c) open eyes accompanied by a visual stimuli, like an intermittent flashlight; and (d) intentional meditation to generate peaceful states of being (Davis et al. 2016, 2017; Davis and Kozma 2018a).

In order to quantitatively classify between modalities and cognitive states, the future of biofeedback systems will need to provide user-friendly interfaces for that purpose. In so doing, the user would be able to learn to discriminate between states with a high degree or level of certainty or significance toward a deeper understanding of the neural correlates of his or her own consciousness. In order to achieve all this, various already available studies from different fields and disciplines, such as mathematics, systems neuroscience, and engineering, among others ought to be combined (Kasabov and Capecci 2015; Davis et al. 2016; Pribram 2013; Kozma et al. 2014). The advances in biofeedback system technologies suggest a new direction to approach the exploration of questions in regard to consciousness and mental activity and how they are reflected in brain dynamics that complements ancient wisdom and philosophical thought (Davis et al. 2015).

Heart Rate Variability (HRV) as a Measure of Psychophysiological Coherence

Heart rate variability has been extensively studied to the understanding, among other things, of the effect of different emotions and their associated stress levels, usually referred to as psychophysiological coherence (McCraty and Childre 2010; McCraty et al. 2001; Childre and Cryer 2008).

There are different ways of experiencing changes in psychophysiological coherence; some are toward higher stress levels, while others are toward more coherent states with an associated significant reduction in stress levels. This can be monitored via a coherence ratio, which is an index that presumably captures the relationship between the two branches of the autonomic nervous system

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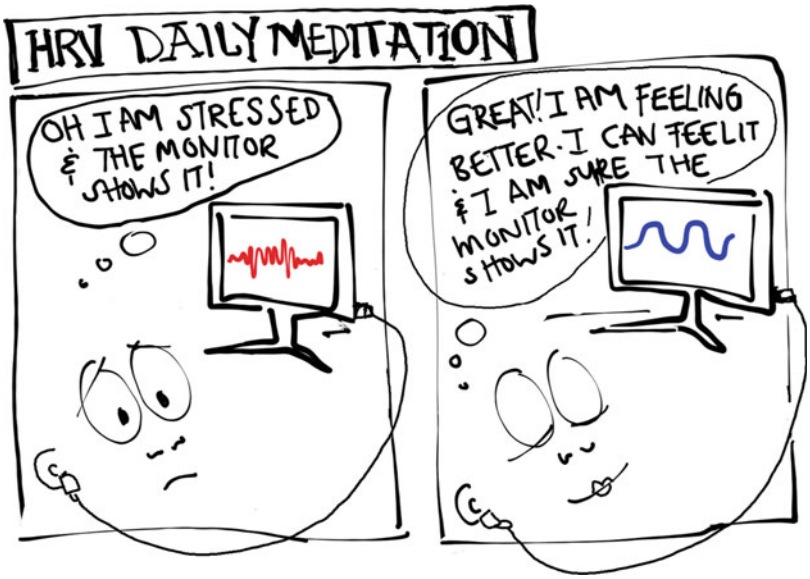
HRV DAILY MEDITATION
OH I AM STRESSED & THE MONITOR SHOWS IT!
GREAT! I AM FEELING BETTER. I CAN FEEL IT & I AM SURE THE MONITOR SHOWS IT!

Fig. 1 Difference in the signals between psychophysiological stressful states and coherent states mediated by meditation. (Art form courtesy of Carey Jackman at The Embassy of Peace, Whitianga, New Zealand)

(sympathetic and parasympathetic) via a Fast Fourier analysis of the HRV signal. There is extensive literature about how to calculate the coherence ratio and how to interpret it or derive other useful signals from it. The brain, heart, and respiration dynamics are essential in mediating psychophysiological coherence, and this is reflected in HRV measurements (McCraty et al. 2006) (Fig. 1).

Several technologies and diverse equipment have been developed for the monitoring of HRV, ranging from clinical and research devices like the Firstbeat monitor (Firstbeat Technologies Ltd. 2017), as well as monitors that can be used on a daily basis by the general population, which are very accessible, like the emWave Technology (HeartMath LLC 2016).

Several authors have studied the relationship between perception, awareness, spiritual experience, relaxation, and general well-being, presumably involving the coupling of the brain and heart, modulated by respiration (Kim et al. 2013; Childre and McCraty 2001). It is important to mention that there is an extensive body of ancient wisdom, philosophical ideas, and hypotheses that emphasize the role of the "heart" in "basic leadership," intentional action, and decision-making (van der Eijk 2007). Much of the advice that we find in various texts suggests different ways in how to handle the "more profound" spiritual experiences (Davis 2009). However, in this section, we focus on the application of HRV and psychophysiological monitoring technologies, which come as a means to assist every human being who is willing to find inner peace and harmony and access high coherence levels, regardless of his or her metaphysical commitments, and, in so doing, create a neutral biological bridge to the different understandings about the subject of inner peace. There are profound implications associated to the use of such devices in fostering individual and social harmony, related to deep feelings of appreciation, love, and compassion (McCraty 2002; Crivellato and Ribatti 2007).

Conclusions and Future Perspectives

Recent studies have shown that the heart is involved in the modulation of physiological states associated with emotions that can lead to stress or tranquility. Mastering desired physiological and cognitive states at will has become almost routine for practitioners of meditation and relaxation, leading to what more recently has been known as psychophysiological coherence or heart cognition (McCraty et al. 2006). We have touched on scientific knowledge applied to the understanding of how to embody peaceful states of being, which

are meaningful and valuable to the individual's decision-making process. We have also mentioned that the combination and proper application of wisdom, science, and technology may lead to individual peace and social harmony, where the ancient art of peaceful living is turned into a science of coherence (Childre and McCraty 2001; McCraty 2017).

To develop inner peace in a way that is meaningful to the individual requires the brain to derive meaning from internal as well as external events that will facilitate the creation of new deeper meanings and a broader knowledge of reality and self (Davis and Kozma 2013; Kozma and Davis 2018). We have highlighted that it remains a mystery to be solved how the brain and heart participate in the creation of trivial and deeper meanings and the fact that in recent years, science has taken an active role in the exploration of this mystery via the art of encephalography and EEG.

We have mentioned that recent technologies have been developed to measure HRV and that studies of heart coherence have flourished, almost as a form of standard language, to build a bridge between subjective experiences, associated with different paths toward inner peace, and objective measures, like the coherence ratio associated with coherent cognitive states. For all practical purposes, in the broader arena of society where secular views merge with spiritual ones, the term psychophysiological coherence refers with great clarity and in a scientific way, to an initial step to "unlock the doors" to higher cognitive meanings in the spheres of psyche, soul, and body (Childre and McCraty 2001).

The ideas presented here have the potential to advance a science that will improve the understanding of values-based decision-making and, we conjecture, will facilitate a change in perception and perhaps in paradigm, for an individual to constructively apply his or her intelligence and choose, at will and consciously, for peaceful behaviors to improve society and leave a better place and possible scenarios of peaceful living for future generations. In all certainty, a good beginning is associated with the use of brain and heart biofeedback systems for stress reduction, relaxation, and meditation.

The new generation of biofeedback systems should aim at an integration with brain and heart computer interfaces that allow the user to learn about his or her cognitive inner states, as part of computer games that are both fun and challenging, to keep the learning process interesting and alive. With the success of such an endeavor, we could aim at inspiring and motivating children, teenagers, and adults ideally from all cultures and places to keep engaged in the quest for inner peace. These games could be interactive between people from different parts of the world who challenge and support each other to develop such skills.

Cross-References

▶ Movie-Making of Spatiotemporal Dynamics in Complex Systems

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Substitutional Reality

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Synonyms

Hybrid Reality

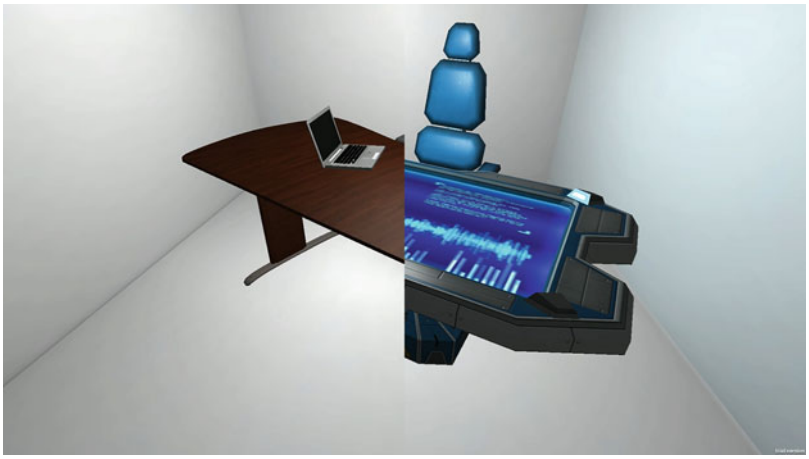
Definition

Substitutional Reality (SR) is a type of mixed reality addressing the disparity existing between a virtual environment and the physical environment in which the user is actually located. While university and professional Virtual Reality laboratories largely consist of empty rooms, especially in the context of domestic environments users are frequently surrounded with physical objects such as furniture, chairs, desks. These objects are not usually part of the virtual environment and might impede the user's experience. In this context, substitutional reality seeks to incorporate real physical objects in the virtual environment, by substituting them with mismatching virtual counterparts. This practice has been found to enhance the experience and believability of being in virtual environments.

Paul Milgram in his Reality-Virtuality continuum imagined a scale ranging from reality to pure artificial reality (Milgram and Kishino 1994). In this scale, we find the known concepts of Augmented Reality and Virtual Reality (VR). *Augmented Virtuality* (AV) is another concept which uses elements of the real world to augment a virtual environment, as opposed to Augmented *Reality*, which uses virtual elements to augment the real world. SR uses the physical objects present in the location a user wishes to experience VR to inform the design of a virtual environment.

The core principle of Substitutional Reality is to substitute these objects with virtual counterparts. This builds on the concept of "passive haptics," the idea of using closely matching physical objects as virtual proxies (Insko et al. 2001). SR differentiates itself on the premise of introducing a mismatch between the virtual object and the physical object acting as a proxy. If there was no mismatch, every substituted object would be a replica. Instead, by considering mismatching substitutions, the range of virtual environments that are possible to create is increased. A real desk in a *substitutional environment* might be substituted by virtual object of approximately the same shape and size, such as a futuristic "holographic table" or by a fantasy stone altar. In this way, if every object surrounding the user is substituted, the user will know that every object they perceive in the virtual environment can be touched (Fig. 1).

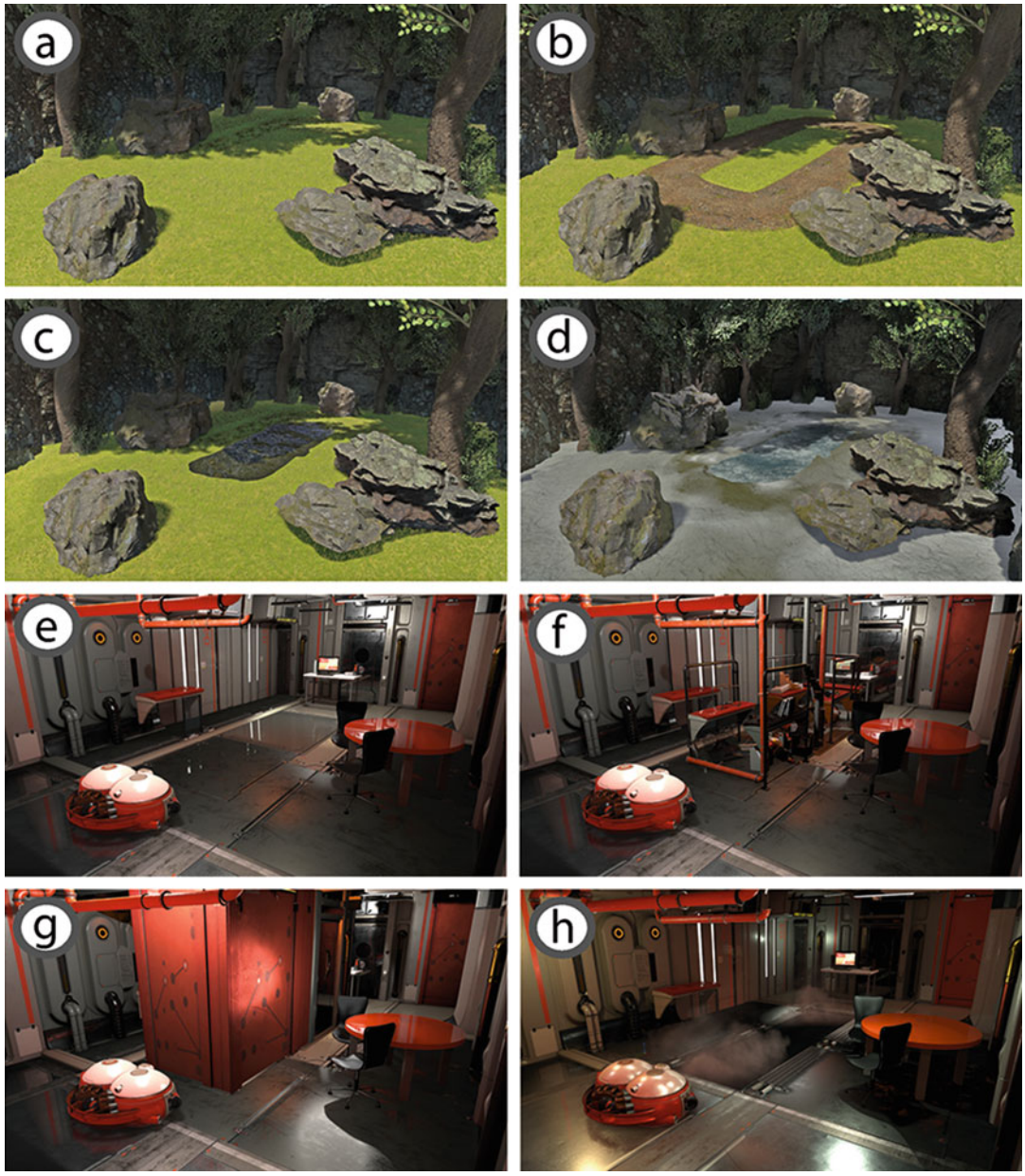
Research on SR first explored the question of how large can be the mismatch between a



Substitutional Reality, Fig. 1 In substitutional reality, physical objects are replaced by mismatching virtual counterparts to enhance the believability of the Virtual Reality experience. Simeone et al. 2015

physical object and its virtual counterpart, before it significantly affects the believability of the experience. In a study by Simeone et al. (2015), participants were immersed in a virtual environment. They were required to interact with a physical object, portrayed as a series of different virtual counterparts. The physical object (a common mug) remained the same throughout the duration of the study, whereas the virtual versions exemplified increasingly different types of alterations, for example, by altering its aesthetic qualities, where the shape and size of the object was kept unchanged but the appearance of the material changed (i.e. glass, wood). More extreme substitutions altered the size of the mug, or the affordances the object suggested. Each participant was asked to rate their experience of interacting with the objects in VR on a range of different factors, such as how much they believed they were interacting with the object they saw, how much the visual representation of the virtual object corresponded to the physical object they were holding, etc. Results indicated that participants could believe they were manipulating the virtual objects, depending on how much the part of the virtual object they were in contact with resembled the physical object's. This indicates that more extreme alterations can be applied to parts less likely to be interacted with. For example, participants believed they were manipulating an oil lamp, an object with a different function than the physical mug that was present in the study, as the oil lamp shared a handle with the real mug (Fig. 2).

The concept of substitutional reality can also be applied to other parts of a virtual environment. A follow-up study (Simeone et al. 2017) explored novel ways to subtly influence users' movement behavior while they are immersed in a virtual environment. Such methods can be useful in domestic environments, for example, to steer users away from fragile objects in their room or lead them towards areas where they can interact with physical objects. A study was devised in which participants were asked to reach three waypoints arranged in sequence in a triangular path. The shortest leg required them to cross a central area of the room (which was empty). Several virtual environments were created following the principles of SR. In these altered environments, the central area was substituted with either surfaces such as water or ice, which indicated that walking over them could be moderately discomfortable or dangerous, or with "immaterial" objects (physical objects that were not backed by physical proxies). The intention was to evaluate whether these alterations were sufficient to change the behavior of the participants, and lead them to take a different route avoiding those obstacles. If users correctly understand the properties of a (virtual) material, they will apply their real-life experience to it. Participants correctly interpreted the water as water and steered clear from it, whereas ice was mistaken as a rocky surface and they walked over it. Similarly, immaterial objects



Substitutional Reality, Fig. 2 The appearance of a virtual environment can affect users' movement behavior, provided that they correctly recognize its properties. Simeone et al. 2017

and walls were able to affect the path users took, even though they were aware that there was nothing in that part of the room.

These studies in the domain of Substitutional Reality inspired other researchers to continue exploring this space. The studies by Simeone et al. involved the manual authoring of virtual environments. Researchers have proposed systems capable of creating these Substitutional Environments automatically (Shapira and Freedman 2016; Sra et al. 2016). Other studies have investigated the design of dynamic props able to accommodate different virtual counterparts (Zenner and Krüger 2017; McClelland et al.

2017). Another direction focuses on the process of substitution itself, by proposing ways in which it might become more seamless (Valkov and Flagge 2017).

In summary, Substitutional Reality is still a developing field. It seeks to provide an answer to the challenge of experiencing VR in domestic environments. Rather than requiring users to radically rearrange the layout of a room to make space to accommodate a VR application, the physical objects in a room are incorporated in the design of the virtual environment, to augment the experience.

Cross-References

- ▶ Everyday Virtual Reality
- ▶ Mixed Reality

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Super Mario Galaxy: An Overview

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Synonyms

Animation; Video games

Definition

Super Mario Galaxy is a video game that is part of the Nintendo Mario franchise. This game was produced originally for the WII but was later made compatible with other Nintendo video game platforms.

Introduction

Super Mario Galaxy is a sequel in the Nintendo Mario franchise to the classic Super Mario 64 and the Mario Sunshine game. What sets this game apart from the previous games is not the 3D animation or the characters but the location where the story takes place. It is centered in deep space, bouncing from galaxy to galaxy, each with its own adventure. Due to this and other features, the game has sold more than 13 million copies and received some of the highest customer ratings for any Wii game (Cable 2020 and Goodall 2021).

The Popularity of Super Mario Galaxy

There is a myriad of things that set Super Mario Galaxy apart from its predecessors in the Nintendo Mario Franchise. The most noticeable difference is the environment in which Super Mario Galaxy takes place: space. This is important for several reasons. First, space is intriguing due to mysterious nature of the environment. Second, this allows the game developers to let their imagination run wild. The result was a large variety of planetoids and other space bodies with different themes. To tie these themes together into one game, the developers grouped the games into galaxies.

Super Mario Galaxy is also set apart by its mechanics. The traditional Mario mechanics were almost completely thrown out the window. The new mechanics were planetoids and Mario's new spin move. Due to the combination the game's 3D nature and planetoids, most of the time Mario is viewed from above instead of the side. This makes the normal stomp attacks very difficult to execute, so Mario was given a new tool in his arsenal: the spin move. This enables Mario to knock the enemies unconscious while remaining on the ground (Super 2021).

Although there have been many Mario games before and since Super Mario Galaxy, it is the first 3D game to have the feature that allows players to play as Luigi. Moreover, this Luigi character comes with a whole new range of challenges. Luigi is faster and can jump higher, with a disadvantage of being hard to stop and drifting while turning. This means that the players can essentially play the same levels twice while still playing a different game (Cable 2020).

SCAR and BAMS Analysis for Super Mario Galaxies

Let's begin with some definitions:

- BAMS Model – BAMS is an acronym for the four major monetary models that lead to the success of the esports industry (Collis 2020).
- Blades – The model in which subsidized platforms (consoles) capture market share to lock in long-term sales (game cartridges) (Collis 2020).
- Advertising and Assets – The model in which games are monetized like traditional sports through advertising and the sale of broadcast rights (Collis 2020).
- Microtransactions – An evolution of the blades model in which games themselves become the sales platform, generating revenue by selling incremental enhancements to their gameplay (Collis 2020).
- Subscriptions – A "magazine-style" revenue model, in which customers subscribe to a game by paying reoccurring fees (Collis 2020).
- SCAR Factors – SCAR is an acronym for the four major factors that propelled the rise of competitive gaming (Collis 2020).

Super Mario galaxy was marketed using the Blades in the BAMS model. Blades is the revenue model where platforms are subsidized in an attempt to lock in the long-term sales of the different games offered by the game manufacturer. This is similar to the way box cutters and blades are marketed. The box cutter is cheap, but the blades are what makes the products profitable (Collis 2020).

Super Mario Galaxy also exhibits many attributes in the SCAR factors. Skill wise, Super Mario Galaxy is not a game that is exceeding difficult to master. However, it is not easy to complete. It is a perfect balance of casual gaming and skill-based gaming. Therefore, it appeals to a much larger segment of players than games that are purely causal or skill based.

Community is another important factor in SCAR. Community is the support that a game receives from its creators and fans. Super Mario Galaxy has had a very large fan base. It is still popular today because of its fan and community bent on playing it even better than before. The accessibility of the game is another factor to consider. The game is very easy to get access to. It has been ported to new consoles such as the Nintendo Switch. The last SCAR factor is reward. Currently there is no large-scale competition for Super Mario Galaxy. Nevertheless, the game is suitable for speed running. There are several websites that

are devoted to just scores and times, so currently the rewards are just leaderboard based (Collis 2020).

Conclusion and Discussion

There have been many Mario games in the franchise since Super Mario Galaxy was released. In Super Mario Galaxy 2 that continued the galaxy storyline, Nintendo took many of the lessons they learned and implemented them in the new sequel (Gamespot 2020). Several of the power-ups from different 3D games are replicated in their new 2D platformers. They also discovered that multiplayer mode is a popular feature. This became evident in later games such as the New Super Mario 2D platformer on WII, which allowed four people to race through the levels and team up to discover new areas. Another popular feature is the central hub which was upgraded in Super Mario Galaxy 2.

In conclusion, Super Mario Galaxy is a great game that will be remembered for its contributions to the Super Mario franchise and the gaming world at large. Although Super Mario Galaxy was not the first 3D game released by the Super Mario Franchise, it was a significant steppingstone to improving 3D games. Super Mario Galaxy dared to go where no other Mario game had gone before: space. This allowed the developers to let their imagination run wild creating various galaxies with various themes and challenges. Many are still remembered to today in modern Mario games from the power-ups that existed in these galaxies. The game developers did not stop there. They introduced planetoids and Mario's signature spin move, which carried on to Super Mario Galaxy 2. The game also adopted the blades revenue model which made it the precursor to one of the most popular revenue models used by modern games today.

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Super Smash Bros Ultimate

► Super Smash Bros. Ultimate and E-sports

Super Smash Bros. Ultimate and E-sports

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Synonyms

Competitive video games; Esports; Nintendo switch; Super smash bros ultimate

With the introduction of Super Smash Brothers Ultimate, the E-Sports scene evolved to adapt to this new iteration in the Smash Brothers series. The competitive fighting genre has held a strong position within E-Sports, and this new release solidified this claim. These two variables are inseparable. The Smash Brothers series continues to be a financial and commercial success. With this addition to E-Sports, the popularity of Smash and E-Sports begins to become more apparent with each passing day.

Definitions

Super Smash Bros. Ultimate is the fifth installment in the Super Smash Bros. series.

Super Smash Bros. is a series of fighting video games created by Masahiro Sakurai and published by Nintendo. The games primarily feature characters from various Nintendo franchises (See Fig. 1).

Nintendo Switch is a video game console developed by Nintendo.

The Announcement and Reception of Smash Ultimate

March 8th of 2018 may have been a normal Thursday for some. But, for a specific group of competitive players, March 8, 2018, was the day that has been long waited for. One of the largest videogame industries in the world broadcasted a video highlighting several videogames set to be released, with a surprise at the video's conclusion. In a matter of just 30 seconds, Nintendo stunned the world with its announcement of the fifth installation of the Super Smash Bros. series: Super Smash Bros. Ultimate. The 8th of March would be marked down in history, not only for Smash, but for E-Sports as well.

There is an overabundance of YouTube videos and Twitch clips covering this surprise announcement. The feedback was a mix of shock and horror (the good kind) and an overwhelming feeling of hype. Smash was back, but it was not alone. This new installation brought with it the biggest roster the entire Smash series has ever seen. Masahiro Sakurai, the creator of the Smash Brothers series, stated that every individual character in every Smash Brothers game would make a return; with some additional new arrivals. The roster has peaked at 80 playable characters, with some newcomers slated to be revealed soon in the Fighter Pass volume 2. This large selection of fighters – one of the largest of its kind – offers players a unique gameplay experience new to the Smash Brothers series. Players must always be vigilant and learn their matchups in order to achieve victory.

As of March 2021, Smash Brothers Ultimate had sold over 23 million copies across the world, marking it as not only the best-selling Smash Brothers game, but the best-selling fighting game ever! It has gone on to win awards such as the Best Fighting Game award at the Game Awards ceremony and the Nintendo Game of the

Super Smash Bros. Ultimate and E-sports, Fig. 1 Ultimate primarily features characters from various Nintendo franchises

Year award at the 2019 Golden Joystick Awards. Ultimate has been critically acclaimed from gamers and journalists alike. On the first day of the Nintendo Switch console's release, 26% of all Switch consumers played Smash Ultimate, naming Ultimate as the hardware that has accumulated the highest amount of sales during the Switch's release. It was also acclaimed as being the most preordered game in Nintendo's history, as well as being the most preordered Smash Brothers game.

Unique Gameplay Dynamics

With this new title, comes unique gameplay dynamics, both new and old. The most famous dynamic is called "tech," which is short for technique. There are different kinds of tech, but the "standard tech" is the most basic. This refers to the short window of time a player's character falls to the floor, and, while pushing the shield button at the right moment (roughly 8–11 frames in Ultimate), the character bounces up into the standing position immediately and negates all damage for a brief moment while getting up. New types of tech, such as footstool techs, can now be achieved. Previous techniques, such as buffering a tech during hitlag, have been brought back from previous generations of Smash. Another skill utilized in all smash games is called "DI." On the Smash Brothers Wiki, this is formally stated as being "the control the receiver of an attack has over their trajectory" (SmashWiki 2021a, b). This means that when the character is hit with an attack, and, by holding the control stick in certain directions during the freeze frames that occur from the attack, the character that was hit can slightly shift the direction they will soar when they are launched.

Competitive Tournaments and E-Sports

Perhaps the largest component that makes up a Smash Brothers game is its relationship with tournaments and E-Sports. The Smash Brothers series were designed to its core to be competitive games, whether it be in E-Sports or with a group of friends. Naturally, Smash Brothers Ultimate and its predecessors have held a position in E-sports tournaments since the first Smash game, but only around 2015 to the present day had it become truly cemented in modern E-Sports. With its newest release, Smash Ultimate has held a strong position in current E-Sports tournaments, such as EVO 2019, Super Smash Con 2019, and Genesis 6. Tournaments such as these are held all across the world, and they have great influence and impact on gamers and E-Sports as a whole.

Conclusion

Smash Ultimate was groundbreaking in terms of competitiveness and dynamics. Smash took the fighting formula and molded it into the ultimate fighting game. With the idea of skilled competition mixed with unique and fun gameplay in mind, Ultimate was able to break the boundaries of what E-Sports are all about. Its impressive roster and re-introduction of gameplay skills both new and old have cemented its position as the best Smash game, and one of the best E-Sports games. With its critical and financial success, Smash Ultimate has secured its place in video game and E-Sports history (Wired, 2018; The Higherlander, 2021).

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▶ Super Smash Bros.: A Brief History

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Super Smash Bros.: A Brief History

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Synonyms

Brawl; For Super Smash Bros.; Melee; Smash; Smash 4; Smash Bros.; Ultimate

Definition

Super Smash Bros. is a platform fighting game where the objective is to rack up percent (damage) on your opponents to knock them off screen.

Introduction

The history of the Super Smash Bros. series of games has been a grand and still progressing task that has no end in sight. This entry offers a brief summary of each of the Super Smash Bros. games in terms of development and competitive scene.

Super Smash Bros. (Nintendo 64: 1999)

Super Smash Bros. on the Nintendo 64 originally started out as a generic platform fighting game called *Dragon King: The Fighting Game*. The creator Masahiro Sakurai presented the prototype to his coworker Satoru Iwata who agreed to help with the project. Sakurai knew that his fighting game needed to include some famous Nintendo characters. Sakurai developed a prototype of the game with four of Nintendo's characters: Mario, Donkey Kong, Samus Aran, and Fox McCloud. The idea was approved, and the game began development and later released on January 21, 1999, in Japan and on April 26, 1999, in the United States. The game had eight playable characters right out of the gate with four hidden characters to unlock. Smash Bros. had a single player mode that played like other arcade games where you fight a handful of characters before you get put up against a boss and a couple other modes like break the targets and board the platforms. The game's focus was its multiplayer mode with four players being able to select their favorite Nintendo characters and duke it out. While this game was a massive breakthrough in fighting games, it is more of a historical piece that feels very clunky today, but this game created the foundation for what was to come out of the series.

Super Smash Bros. Melee (Nintendo GameCube)

Super Smash Bros. Melee is often praised as the best game in the series that had a very short development period. With only 13 months to develop the game, Masahiro Sakurai came back as director and wanted to make this "the sharpest game in the series." The game launched on November 21, 2001, in Japan and on December 3, 2001, in North America, and it was praised as one of the best games on the Nintendo GameCube. The game had 14 playable characters out the gate and 11 more to unlock with a total of 25 playable characters. The game had returned to single player modes and added new ones such as adventure mode, events mode, and homerun contest. While the single player mode is always fun, the multiplayer mode was considered the peak of the series. The game added a couple new inputs to give players even more options to attack and evade.

Super Smash Bros. Melee was and still is the most popular Smash Bros. game competitively in the series with a big player base and tournaments still going on today. The game is considered the fastest and most competitive Smash Bros. game to watch.

Super Smash Bros. Brawl (Nintendo Wii)

Super Smash Bros. Brawl started development without the creator Masahiro Sakurai even

knowing. Due to his departure from the game's original studio, Sakurai thought Melee was his last game in the series. However, due to Melees positive reception, Nintendo began development on Brawl when the Wii was first announced. Brawl was released on January 31, 2008, in Japan and on March 9, 2008, in North America. Super Smash Bros. Brawl had 39 playable characters with 2 of them being the first third-party characters in the series.

Brawl had a huge competitive scene in the beginning and quickly died down as the game was considered too slow for most competitors and it lacked a lot of the technical aspects that the previous game in the series had.

Super Smash Bros. 4 (Nintendo 3DS/WiiU)

Super Smash Bros. 4 began development in early 2012 and was going to be the first HD game in the series as well as the first Smash Bros. game for the Wii U and 3DS platforms. The game was released on the 3DS in October 2014 and then on the WiiU in November 2014. The game had a massive roster of 58 characters to play and new single player modes.

The game was considered not as fast as Melee and not as slow as Brawl but a good balance between the two. The game's competitive scene was very big on release, and many top players came to take the title as best in the world. However, one of the DLC characters – Bayonetta – began to plague the competitive, with her zero to death combos. As a result, the competitive scene began to die down quickly because many players believed that the game's characters were very unbalanced.

Super Smash Bros. Ultimate (Nintendo Switch)

Super Smash Bros. Ultimate did not have much information about its development. Ultimate started development when the last DLC fighters were coming out on Smash 4 in 2015. The main highlight of Smash Ultimate was that every fighter that has been in a Smash Bros. game is going to come back. Smash Ultimate reused a lot of assets from Smash 4 to make development smoother. The new game was released on December 7, 2018, and was considered as the best in the series. Smash Ultimate was launched with 74 fighters, 11 of those being new, and 12 more new DLC fighters were developed.

Ultimate brought a new single player mode called spirits and a revised classic mode that pits every fighter in unique scenarios that would fit those specific characters.

Smash Ultimate started out with a Nintendo-held tournament before the release of the game to show off its new mechanics and competitive aspects of the game. Smash Ultimate is considered the best modern competitive smash game whereas Smash Melee is still being considered by many to be the best in the series (Wired 2018; The Highlander 2021).

Cross-References

▶ Super Smash Bros. Ultimate and E-Sports

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Wired.: Super Smash Bros. Ultimate is a massive monument to itself (14 December 2018).

Surgical Navigation

▶ Augmented Reality in Image-Guided Surgery

Surprise Mechanics

▶ Loot Boxes: Gambling-Like Mechanics in Video Games

Survival

▶ Fortnite: A Brief History

Survival Horror

▶ Dead Space Through the Lens of Resonance
▶ Resident Evil 2, History of

Symbolic Planning in Computer Games

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Introduction

Symbolic planning refers to finding a plan containing actions by identifying actions relevant to achieving the specified goal and ordering these actions whose preconditions and postconditions (also known as *effects*) are explicit, by considering causal dependencies among them and avoiding conflicts. This distinguishes it from other kinds of planning in which actions or their preconditions or effects are not explicitly specified. Planning is different from scheduling. Planning involves selecting relevant actions and ordering them. Scheduling involves assigning start times and resources to preselected activities. Symbolic planning is relevant to all computer games in which interacting actions must be ordered or must occur in parallel, for a meaningful gameplay, such that the selection of actions and the type of their occurrence (sequential or concurrent) are based on reasoning about their preconditions and effects. Actions may be selected and ordered by a computer, or human player, or game designer, or action selection and action ordering may emerge during a gaming session. Symbolic planning can be used to verify that players can achieve goals with the available actions. It can be also used to identify if states from which a goal is not achievable can be reached. If such states exist, (i) the game design can be changed so that the states from which the goal is unreachable are unreachable, or (ii) new actions can be introduced in the game, and symbolic planning can be used to confirm that the goals are achievable using the new actions, and also provide relevant action orderings, if needed. Symbolic planning can also be used to identify the states of a game from which a goal is hard to reach, so that the game's design can be modified, to provide shortcuts to the player, if needed. Symbolic planning can be used to check if actions can occur concurrently without a conflict. Symbolic planning along with the estimated durations of actions and the estimated player-response times can be used to estimate the duration of a gaming session or a gaming episode. Symbolic planning can also be used in the design and control of the characters and objects which have no central role in a game and are included to mainly make the game interesting. An optimal planner finds a plan which minimizes the given objective function, like the total resource consumption or total execution time. Such traditional objective functions are not always suited for computer games because of the objectives of entertaining, educating, or surprising the player. This entry is a comprehensive survey of various ways in which symbolic planning has been used in computer games.

Terminology

Classical Planning: It is the problem of selecting and ordering directly executable actions, such that the actions can be executed in a manner consistent with the ordering, to achieve the given goal from the completely specified initial state, assuming perfect perception, deterministic actions, and a static and completely observable environment. Classical planning serves as the foundation for planning under uncertainty, e.g., conformant planning, probabilistic planning, and decision-theoretic planning.

STRIPS Planning: It is a special case of classical planning in which actions are instantaneous, the preconditions and effects of actions are pure conjunctions of function-free ground literals, and

there are no negated preconditions. If the execution of an action denoted by a' makes p true, then p appears in the list of *add effects* of a'. If the execution of a' makes q false, then q appears in the list of *delete effects* of a'.

Progression Planning: Also known as *forward state-space (FSS) planning*, it is a domain-independent approach to planning which finds a plan by generating a space of states beginning with the initial state, by applying actions until a state containing the specified goal is found. When progression planning is used to solve an instance of classical planning, all states generated by it are completely specified because of the assumptions of classical planning which prohibit any kind of uncertainty. Actions in the plans found by FSS planners are contiguous.

Regression Planning: Also known as *backward state-space (BSS) planning*, it is a domain-independent approach to planning which finds a plan by generating a space of states beginning with the goal, by applying actions until a state subsumed by the initial state is found. Actions in the plans found by BSS planners are contiguous.

Partial-order Planning: Also known as *least-commitment planning* or *causal-link planning*, it is a domain-independent approach to planning which finds a set of step-action bindings along with a partial ordering over the steps, such that the specified goal can be achieved by executing the actions bound to the steps in a manner consistent with the ordering over the steps. Steps are necessary to distinguish between multiple occurrences of an action in a plan. Since actions are not contiguous, it is possible to incorporate new actions in an existing plan if it becomes necessary due to changes, like a change in the goal which may occur between plan synthesis and plan execution. New actions can also be incorporated into the existing plan during its execution, if there is no conflict.

Causal Link: A causal link exists from a step denoted by s' to a step denoted by s" if s' is bound to an action which adds p which is also a precondition of the action bound to s", and the partial-order planner decides to use s' to supply p to s". s' is also known as the *producer* or *establisher* or *contributor* in this causal link. s" is known as the *consumer* in this causal link. This causal link is threatened if a step denoted by s'" can occur between s' and s" such that s'" is bound to an action which deletes p. Such a threat can be resolved by (i) including an ordering forcing s'" to occur before s', or (ii) including an ordering forcing s'" to occur after s", or (iii) including a new step denoted by s"" and binding it to an action which adds p and including a causal link in which s"" provides p to s", and including an ordering forcing s"" to occur after s'", and removing the causal link in which s' supplies p to s". Resolution (i) is also known as *promotion* because forcing s'" to occur before s' is like promoting it in the ordering of the steps for execution. Resolution (ii) is also known as *demotion* because forcing s'" to occur after s" is like demoting it in the ordering of the steps for execution.

HTN (Hierarchical Task Network) Planning: It is an approach to planning which uses domain-specific knowledge for speeding up plan synthesis, or for synthesizing a plan conforming to user intent, such that the domain-specific knowledge is provided in the form of HTNs. The tasks in an HTN may be primitive or non-primitive. A primitive task is not decomposable. Primitive tasks are actions. A non-primitive task is decomposed using primitive or non-primitive tasks. The specification of an HTN denoted by T contains a top-level goal which is achieved by choosing and ordering the actions that appear in the specification of T and/or the actions in the specifications of non-primitive tasks appearing in the decomposition hierarchy relevant to T. An HTN may also contain causal links and orderings over primitive or non-primitive tasks. HTNs make it possible to plan in a top-down fashion by comparing the goal of the given planning instance with the goals fulfilled by different HTNs provided for the planning domain, and selecting suitable HTNs, and selecting and ordering actions from their decomposition hierarchies.

Case-Based Planning (CBP): It is inspired by case-based reasoning (CBR). There is a library of cases such that each case in the library has the initial state and goal of a planning instance along with its plan and contextual information. When a new planning instance is received, the closest case from the case library is retrieved using similarity

criteria, and the solution from this case is adapted to solve the given instance. If there is no case in the library which is sufficiently close, the new instance is usually solved from scratch and a new case may be added to the library.

Symbolic Planning for a Consistent, Flexible, and Robust Gameplay

The narrative provided by an interactive narration system emerges from the interaction of the human player with the digital narration system. A symbolic planner is used in Shoulson et al. (2013) for finding a sequence of authored events which achieves the given goal configuration of objects and actors from their given initial configuration. There is a tradeoff between incorporating flexibility in interactive narration and the computational complexity of finding narrative plans. The higher the flexibility, the larger the worst-case search space for the narrative planner. Also, though giving a lot of flexibility to a narrative planner can result in surprising narratives, not all of these may be interesting to the human player. The narrative planner in Shoulson et al. (2013) searches in the space of sequences of events instead of the space of sequences of actions of individual characters. The former search space is much smaller. Event participants are autonomous between execution of events. The events are manually authored. An event consists of event behavior, event cost, the number of objects that can participate in the event along with their roles, precondition function, and postcondition function. The precondition function returns true if and only if the given objects can play the specified roles and also satisfy the authored preconditions of the event. The postcondition function changes the world state according to the authored postconditions of the event. The planner in Shoulson et al. (2013) can react to the user's actions and replan from the current state.

The importance of temporal issues in interactive storytelling is emphasized in Porteous et al. (2011). Some preconditions of actions need to be true over the entire durations of these actions, not just at the beginning. Some actions must occur in parallel for them to be meaningful in the game. The duration of an action is explicitly included in its description in Porteous et al. (2011). Furthermore, it is explicitly stated for each action precondition if it should be true at the beginning or end or the entire duration of execution of the action. Also, it is explicitly stated for each action effect if it is achieved at the start or end of the duration of the action. This action-description format is supported by version 3.0 of PDDL (Planning Domain Description Language) in Gerevini and Long (2005).

MIMESIS, a system for interactive storytelling, is presented in Young and Riedl (2003). Narrative planner is one of the components of its architecture. The narrative planner accepts descriptions of all actions that can be performed in the virtual world and the goal of the intended story, and searches the space of action sequences to find a story plan. The *discourse planner* accepts the story plan and the communicative actions to be used to convey the story. Communicative actions include narrative voice-overs, use of background music, and directives for a camera controller. Use of *narrative mediation* to handle an unanticipated activity of a user of MIMESIS is reported in Riedl et al. (2003). There are two kinds of narrative mediation: *accommodation* and *intervention*. Accommodation allows a user action threatening the precondition supported by a causal link or not achieving this precondition when in fact the user should perform an action serving as the contributor of the precondition, to occur, and changes the gaming world to make the deleted or unachieved precondition available for the consumer in the causal link. Replanning is a less preferred kind of accommodation as it can be computationally expensive. Intervention replaces the effects of the user action conflicting with the narrative with alternate effects that are compatible with the narrative. Intervention is essential when the user's action deletes a condition that cannot be added again. HTN planning is used in Cavazza et al. (2002) to find plans for individual characters for interactive storytelling. The tasks in their HTNs are totally ordered as in Nau et al. (1999).

Concurrent plan augmentation (CPA) is proposed in Elogeel et al. (2015). CPA involves identifying the ways in which a gameplay can deviate

from the intended execution of a tactical plan denoted by P', and coming up with a separate plan denoted by P" which protects the execution of P' by preventing deviations from P' or remedying the deviations from P', so that there are no damaging deviations. P' and P" are executed in parallel. CPA can be computationally cheaper and more reliable than replanning. The probability of failure of each action in P' is estimated using gameplay statistics. These probabilities are useful in finding plans that protect and remedy.

Symbolic planning is used in the design and implementation of the game master (GM) for role-playing games in Luong et al. (2017). The GM is responsible for setting up the game environment, managing the narrative flow, and enforcing the game rules. A tree containing goals, subgoals, and the actions for achieving them was manually created in this work, for the GM to use. Creating alternate plans for achieving a goal or subgoal is necessary for a flexible and robust gameplay.

Symbolic Planning for Incorporating Humor

It is reported in Olsen and Mateas (2009) that most humor in commercial computer games is language-based and hand-authored. They report on a system which models physical humor. This kind of humor arises out of funny motor actions. It is language-independent and culture-independent. They use HTN planning to find plans whose execution results in physical humor.

Symbolic Planning for Simulation

An approach to automatically populate virtual reality simulations with many characters is presented in Trescak and Bogdanovych (2017). They simulate agents' needs. Goals are automatically derived from these needs. They use case-based planning to find plans for agents. Though no game is reported in this work, such simulations can be gamified. Symbolic planning is used in Caruso et al. (2013) for generating data fast in a scalable and cost-effective manner. They generate plans for various goals related to the operation of smart homes. A valuable side effect of the execution of the synthesized plans is the data generated. Such data can be useful in building actual smart homes. Their approach has the following three stages: (i) Activities performed daily, like taking a shower and drinking milk in the morning, and optional activities like watching TV, are chosen along with the number of their occurrences, to generate high-level activity sequences. (ii) Planning instances based on the activity sequences from stage (i) and the available virtual environment are generated and solved, to have plans for completing the activities. (iii) The plans generated in stage (ii) are executed in the virtual environment, and measurements from the virtual sensors are collected. These measurements can be used to estimate the energy consumption in a smart home.

Symbolic Planning for Educating and Understanding Humans

A comparison of the conflicts in stories that are detected by people and the conflicts due to threatened causal links in these stories is reported in Ware and Young (2012). The latter conflicts can be found automatically. The goal of this study was to understand the differences between the human model of conflict and the computer model which treats a threatened causal link as a conflict. This understanding can be used to improve the design of computer games. Symbolic planning is used in Siddle et al. (2017) for generating plans for eating that are in compliance with or are violations of the recommendations for eating after a bariatric surgery. At logical level, the number of ways to violate health recommendations is exponential in the number of health recommendations when the health recommendations are independent of each other and cannot be split further into multiple health recommendations. Animations showing the execution of compliant and noncompliant plans for eating are created. The viewers of these animations answer questions about compliance and noncompliance. The viewers' responses are assessed, to rate their knowledge of the eating guidelines,

and to also evaluate the effectiveness of the 3D animations. There is no computer game reported in Siddle et al. (2017), but their implementation can be gamified, e.g., a human player can be given a chance to interactively change the eating plan being executed, and points can be awarded when the player enforces compliance by replacing any of the existing noncompliant choices by a compliant choice, and points can be deducted when the player violates any of the health recommendations by replacing any of the existing compliant choices by a noncompliant choice.

Conclusion

Symbolic planning has made important contributions to computer games. It has been useful for educating, entertaining, assessing, and understanding human players. The role of symbolic planning in simulations and serious games has potential to reduce costs, and save time and resources in real world. Still, the role of symbolic planning in many computer games has been described using only examples and case studies. This makes it difficult to formally evaluate the impact of symbolic planning on these computer games and provide guarantees.

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Synchronization

► Distributed Simulation and Games

T

Tabletop Storytelling

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Synonyms

3D animation visualization; Holographic filmmaking; Mixed reality stories

Definitions

In tabletop storytelling, a 3D animated story is presented to the viewer as a hologram on a given plane in reality such as a tabletop. Every 3D animated story can be presented in augmented reality. Special augmented reality visualization techniques are required such as glasses or phones. The user becomes the cinematographer and can watch the story from the desired perspective. Moreover, simple types of interaction can be included to personalize the way the story is shown to the viewer.

Introduction

Storytelling takes place in various different formats. The most basic form is verbal storytelling during a conversation. Stories can be written text as well as illustrations only. Most of the time storytelling happens through a combination of mediums. The more accurate information is transmitted, the less room for interpretation of stories is left to the person that listens, reads, or watches a story.

Storytelling is an important factor for children growing up and it follows us through our journey of life. Through the history the methods of storytelling have evolved (Yılmaz and Ciğerci 2019; Kosara and Mackinlay 2013). Starting from mural paintings in caves, continued by verbal storytelling and finally written stories, modern everyday storytelling happens through images and videos. Tabletop storytelling uses holograms on top of physical surfaces for the purpose of visualisation. Tabletop stories can be narrated. They aim to present a completely natural way of watching a story similar to observing scenes in real world. Depending on the holographic rendering quality of the story and the device through which the story is consumed the degree of realism varies.

Holographic Content Creation

Tabletop storytelling offers two possibilities of scene setup: static and dynamic. In the static

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theater setup, the whole scene is shown to the user all the time and the user can change the viewpoint depending on where the action happens. The user experiences a small-sized theater on a tabletop. In the dynamic setup, the scenes change throughout the story. During scene changes, the user needs some time to experience the new virtual environment.

Existing animated stories are transformed into a tabletop story. Stories consisting of animated 3D objects are converted into scenes such that the viewer can watch from every angle. Existing plays and movies are recorded using volumetric capture technology (Yu et al. 2021) to produce photorealistic tabletop stories.

Interaction

In tabletop storytelling, the viewers select the perspective in which they want to watch. Moreover, they have the option to modify content that appears in the story (Aurelia et al. 2014). In some stories they can change the appearance of characters and objects. In other stories they can even change how the story develops by choosing between multiple story lines (Li et al. 2022). The viewers' role ranges from passive observer to cinematographer, to director, and even to writer.

Presenting a Tabletop Story

Tabletop storytelling relies on artificial reality systems. A mixed reality system scans the physical environment the viewer is in and positions the story on a surface. Moreover, the viewer has the possibility to change the surface or place the story in the air. Depending on the device the viewer is using they see a 2D augmented or a holographic view of the story embedded into the environment. When using mobile devices such as phones and tablet computers, viewers see a 2D view of the story augmented on the tabletop. When using head-mounted mixed reality displays the tabletop story appears as a hologram. Stereoscopic displays (Lin and Woldegiorgis 2015) are placed on tabletops to present a 3D view of stories from somewhere within a 180 degree angle.

Conclusion

Tabletop stories provide an engaging way to consume content. In combination with volumetric recordings, they achieve a high degree of realism. It allows the viewer to have a tabletop-sized theater in their home which they can carry with them everywhere they go. Depending on the level of interaction a dynamic story allows the viewer to touch, grab, and move objects inside the story. For visualization, augmented reality mobile devices can be used. However, head-mounted displays offer a more intuitive holographic experience.

Cross-References

- ▶ Holography, History of
- ▶ Mixed Reality
- ▶ Mixed Reality and Immersive Data Visualization

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Tactile

▶ Tactile Visualization and 3D Printing for Education

Tactile Visualization and 3D Printing for Education

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Synonyms

3D Printing; Additive manufacturing; Haptic; Physical visualization; Rapid prototyping; Tactile; Touch; Visualization

Definition

Tactile visualization is the process of formation of a mental image based on a sense of touch. In particular, objects for tactile visualizations can be created using 3D printers based on digital 3D models stored in a computer.

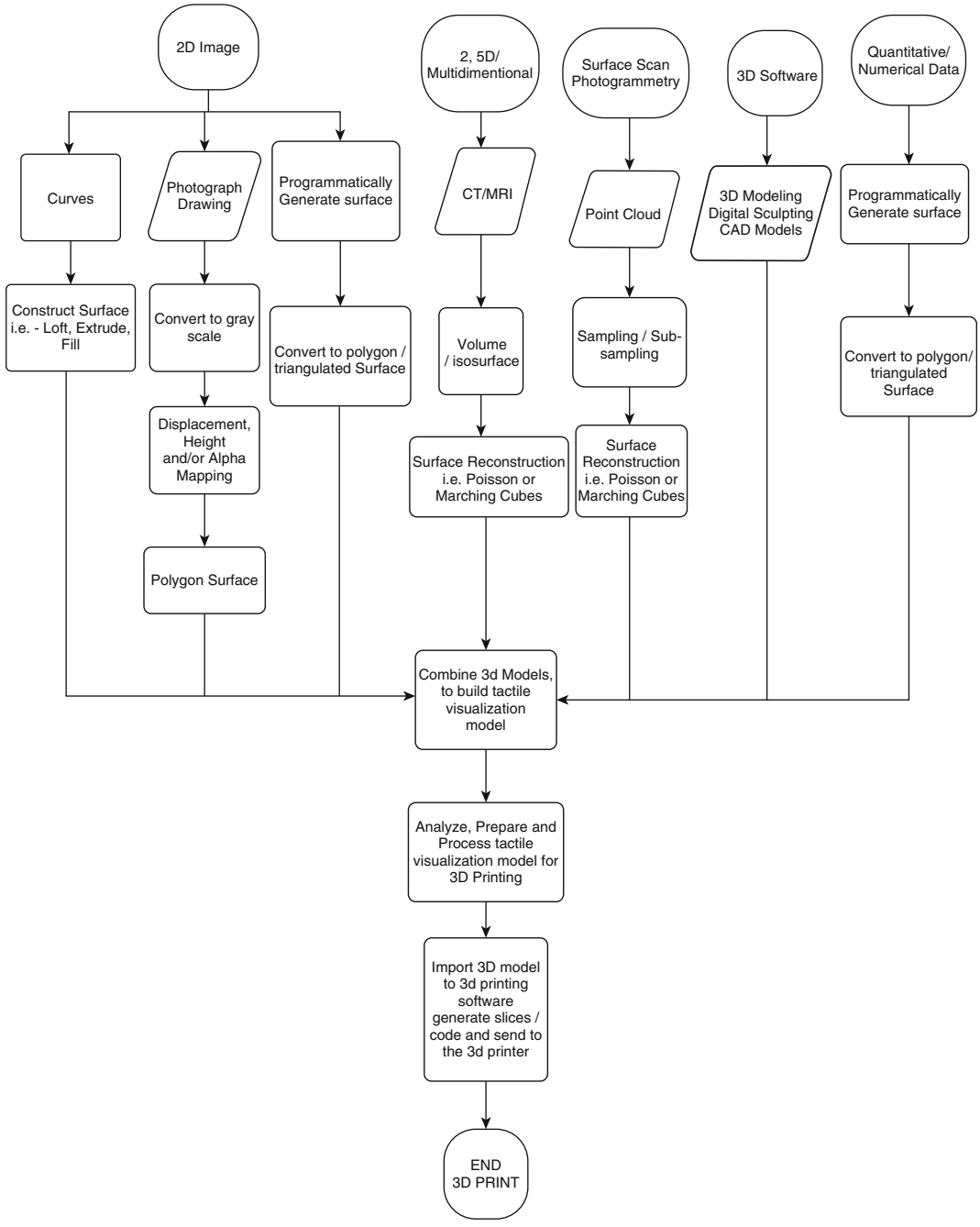
Introduction

The earliest data visualizations were, most probably, physical – built by arranging stones or pebbles and, later, clay tokens (Schmandt-Besserat 1999). Since then, many new technologies for fabrication of objects have been created. Currently, advances in rapid prototyping technology has allowed for the widespread of consumer level 3D printers. The accessibility of these printers allows us to demonstrate very sophisticated physical visualizations that were previously impossible. As a result, 3D printing becomes a very useful technology for creation of innovative educational material. Research has shown that spatial memory and object recognition are both accessed with tactile senses (Xiao 2011). However, since 3D printing for education is still at its infancy, there is no general approach to the creation of 3D-printed material. Specifically, the input data describing an interesting object or phenomenon can be converted into a 3D model via a number of approaches. Here we provide an overview of different methods for 3D conversion that take into consideration dimensionality of the initial data set (2, 2.5, or 3) and the source of the information (2D image, collection of 2D images, 3D scan). Next we discuss further processing and improvement of the output 3D model, such as fusion of multiple models and incorporation of additional information that can be used for improved 3D visual and tactile perception. Finally, we discuss transition from a 3D model to a 3D-printed object and describe pluses and minuses of currently available 3D printers.

State of the Art

One of the challenging steps in creating a tactile visualization is a conversion from the initial data source into printable digital 3D model. Figure 1 summarizes many possible inputs and data transformations all resulting in 3D printing. The input data comes in many different formats; thus, generation of a 3D digital representation can be time-consuming. We use various approaches depending on the data types and desired outcomes. For example, when working with scientific multidimensional images from such sources as computer tomography (CT) scans that are combined from a large number of 2D images, we use ImageJ and Kitware ParaView to define and generate isosurfaces (Rengier et al. 2010).

In the situation when only one 2D illustration or graphic needs to be converted into a 3D surface, then we need to use color information from the image to create depth or displacement maps. They can be later "extruded" in a computer graphic application or using specialized software. Next, the generated 3D surfaces are saved as polygon meshes.


2D Image
2, 5D/ Multidimentional
Surface Scan Photogrammetry
3D Software
Quantitative/ Numerical Data
Curves
Photograph Drawing
Programmatically Generate surface
CT/MRI
Point Cloud
3D Modeling Digital Sculpting CAD Models
Programmatically Generate surface
Construct Surface i.e. - Loft, Extrude, Fill
Convert to gray scale
Convert to polygon / triangulated Surface
Volume / isosurface
Sampling / Sub-sampling
Convert to polygon/ triangulated Surface
Displacement, Height and/or Alpha Mapping
Surface Reconstruction i.e. Poisson or Marching Cubes
Surface Reconstruction i.e. Poisson or Marching Cubes
Polygon Surface
Combine 3d Models, to build tactile visualization model
Analyze, Prepare and Process tactile visualization model for 3D Printing
Import 3D model to 3d printing software generate slices / code and send to the 3d printer
END 3D PRINT

Tactile Visualization and 3D Printing for Education, Fig. 1 Schematic of different approaches to 3D printing of tactile visualizations depending on the data input

After the creation of individual 3D models and corresponding meshes, the models can be further improved, combined, or enriched with additional information. Joining the models requires positioning and scaling the objects in a 3D virtual space. Multiple tools and techniques are used to further process, clean, and manipulate parts of the geometry in order to achieve accurate results. To

assist with this stage of the process, we use 3D computer graphic software, such as Autodesk Maya or an open-source application Blender. It is a critical step of the process, since it determines the final look and feel of the 3D model. The model is saved and then exported as either an.OBJ or. STL file. Prior to exporting the models into a 3D printing software (traditionally called Slicer), the models have to be analyzed, prepared, repaired, and processed.

Other approaches to the creation of 3D models include free-form modeling, surface scanning, and surface rendering must go through this same process in order to be 3D printed. For this task, we use either freeware Autodesk MeshMixer or an open-source software for processing unstructured polygonal meshes called MeshLab. These applications check the printability of the geometry and make the necessary repairs. Again, once the model has been properly analyzed, it is exported as an.OBJ or.STL and imported into the 3D printing software (Slicer).

The Slicer allows adjusting parameters of the printer directly affecting the final physical 3D-printed object. There are various Slicing software packages, each offering different customizing options. However, typical parameters include layer thickness, infill, and number of shells. Layer thickness is the resolution of the print and refers to the height that will form each layer of the print. Infill is the setting that determines the ratio up to which the object is going to be filled with the material (0 % means that the object will be completely hollow, and 100 % means completely solid). Finally, shells are used to strengthen and thicken the walls of the object.

Additionally, some printing software packages have settings for automating support structures for holding overhanging geometry, rafts for added support in holding the object to the 3D printer bed, and, in the case of multiple extrusion printing, selection that allows a 3D model to be printed using a specific extruder. The 3D Slicing software also allows for position models on a virtual 3D print bed showing actual size and helping to optimize orientation for better quality and faster printing.

3D Printing Hardware

There are many types of three-dimensional (3D) desktop printers. The majority of low-cost consumer 3D printers are FDM (fused deposition modeling), where objects are built up layer by layer with extruded melted plastic. The examples of materials currently used for 3D printing include such biodegradable plastic as polylactic acid (PLA), an environmentally friendly material derived from corn starch, and acrylonitrile butadiene styrene (ABS) polymer derived from fossil fuels. There are a number of transparent, conductive, wood, dissolvable, and other materials with advanced properties, including chocolate and biological cells that can be used for 3D printing. Some of these materials require specific hardware for extrusion and temperature control. Most of the polymers are produced as filaments with a diameter from 1.75 mm and 3 mm, depending on the printing head type. They melt at temperatures ranging from 170 to 250 degrees Celsius, and when they rapidly cool down, they form complex 3D objects, layer by layer. The cost of a consumer-grade, desktop 3D printer ranges from $300 for do-it-yourself (DIY) kits to $3,500 for pre-assembled, larger build area, systems. Many of them can be purchased on the Internet. Most 3D printers are compatible with standard.STL (stereolithographic) and.OBJ file formats.

As other forms of 3D printing based on stereolithography (SLA) become more accessible to the academic community other materials, such as metals, flexible polymers, and castable and high-stress resins become available. In the future, combinations of different materials together with the use of various advanced settings and improved resolution will ultimately lead to a higher quality and accuracy of tactile visualizations (Table 1). Additionally, this will allow using material properties, such as texture, elasticity, and thermal conductivity to encode and communicate more types of data in the same model (Padilla 2009).

For this study, we tested numerous 3D printers. We found that most low-cost consumer 3D printers have similar features, resolution settings, and overall output quality. However, during our

Tactile Visualization and 3D Printing for Education, Table 1 3D printer data (Kaplan, Pyayt, University of South Florida)

Printer	No. printers	Print count	Build size	Resolution	Material	No. extruders
Makerbot Replicator 2	10	1769	28.5 L × 15.3 W × 15.5 H cm	100 μm	PLA	1
Makerbot Replicator 2X	2	74	24.6 L × 15.2 W × 15.5 H cm	100 μm	ABS/ PLA	2
Makerbot Replicator 5th^{Gen}	2	13	25.2 L × 19.9 W × 15.0 H cm	100 μm	PLA	1
Makerbot Replicator Z18	2	47	30.0 L × 30.5 W × 45.7 H cm	100 μm	PLA	1
Deltamaker	1	13	24 cm diameter × 26 H cm	100 μm	PLA	1
Orion	1	15	12.7 cm × 12.7 cm × 22.8 cm	100 μm	PLA	1
Rostock Max	2	31	28 cm diameter × 39 H cm	100 μm	PLA/ ABS	1
Creatorbot	2	15	30.5 cm × 30.5 cm × 45.72 cm	100 μm	ABS	2
Makergear M2	1	15	20 cm × 25 cm × 20 cm	100 μm	PLA/ ABS	1
MakerFarm Prusa	2	5	30 cm × 30 cm × 34.3 cm	50 μm	PLA/ ABS	1
FlashForge	3	64	22.5 cm × 14.5 cm × 15 cm	100 μm	PLA/ ABS	2
Form1+	2	39	12.5 cm × 12.5 cm × 16.5 cm	25 μm	Resin	1(tank)

testing, we did find out that some printers were more consistent than the others. Typical problems with 3D printers include warping, lifting or shifting, and leveling/un-leveling of the print plate. The ability to maintain the appropriate temperature and jamming of the extruder were also problem areas for many of the printers. However, there were several that performed really well. For example, the Makerbot Replicator 2 4th-generation printers produced finished prints more often and had significantly fewer issues than many other models. This printer comes pre-assembled, uses PLA, and is equipped with a single extrusion nozzle. As of 2015, it ranges in price from $2199.00 to $2800.00 and can be purchased online.

Another example of a printer that consistently produced good results was the Rostock Max. This DIY printer uses a cylindrical mapping motion to build prints along the XZY axis. The printer has a heated build plate, large printer volume area, can print in PLA or ABS, and is a single-extrusion printer. The Rostock Max kit costs $1000.00 and took us 3 days to build. These two printers are just the examples of good-quality models that we tested, while there are many more available on the market.

In conclusion, we also found that different printers fit different departments and colleges. For example, engineering students liked the DIY printers because they allowed them to customize and modify the printer to their particular needs. Whereas students in other disciplines, such as the arts, liked the ease of use and available technical support of the preassembled printers.

Overview

Data visualization is a technique used to explore real or simulated data by representing it in a form more suitable for comprehension (Fritz and Bamer 1999). In schools and universities, most educators utilize generic two-dimensional scientific illustrations, and data visualizations. These graphics require students to mentally decode, rotate, and visualize the object, adding to the complex mental processing already taking place

through the introduction of new learning material. It is especially challenging when understanding requires complex geometric manipulations in three dimensions.

To decrease the cognitive load imposed on students and explain complex engineering, science, and art concepts easier, we are using tactile visualizations created with 3D printers. Tactile visualization, similarly to 2D data visualization, can be used as both explanatory and exploratory learning tools. Exploratory visualizations are used to better understand the data. Explanatory visualization is utilized as a method of communication to explain something about the data (Iliinsky and Steele 2011). Tactile visualizations allows for deeper explanation and exploration through providing physical representations that allow the learner to feel and touch the data, in addition to seeing. Furthermore, numerous evidence from educational psychology suggest that physical manipulative representations of complex objects facilitate understanding and learning (O'Malley and Fraser 2004). Additionally, building tactile data representations allows customizing and individualizing of educational material.

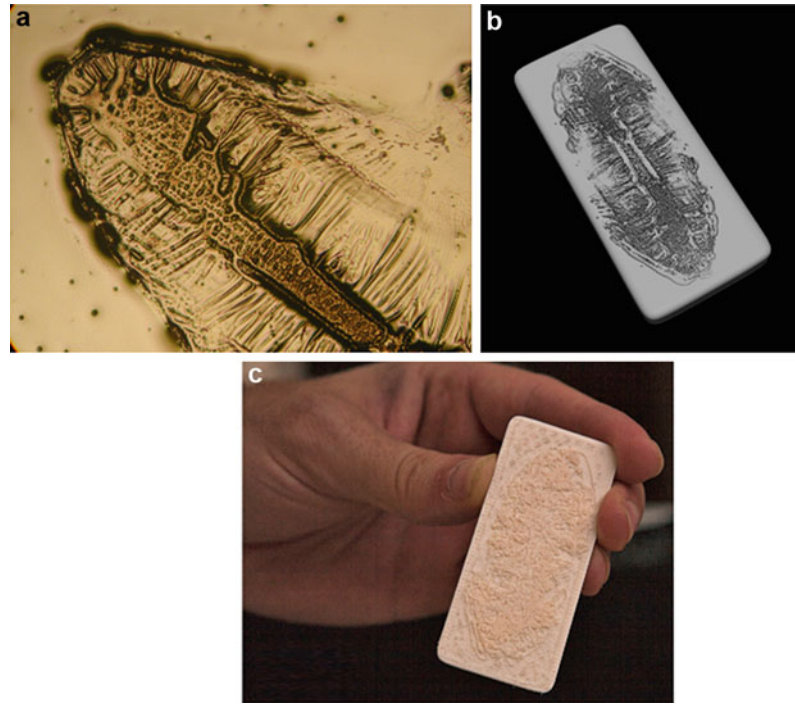
Our approach is to provide the students with physical and tactile representations of complex objects created by other people, as well as give them an opportunity to create tactile visualizations themselves. It helps more effectively and efficiently to aid in the development of mental images, transfer of prior knowledge to new context, improve mental processing, and positively contribute to learning experiences in STEAM (science, technology, engineering, art, and mathematics) education. We investigated and categorized multiple approaches to the creation of tactile visualizations for numerous departments: Computer Science, Paleontology, Geology, Chemical, and Biomedical Engineering from the College of Arts and Sciences and College of Engineering, as well as the Colleges of Education. Furthermore, we see educational value in the use of tactile visualizations for the learners with special needs and disabilities. In particular, tactile visualizations can greatly enhance education of visually impaired students.

Experiments and Showcases

In the following section, we show some of the approaches that were utilized to generate tactile visualizations for several educational modules. The design and results of the tactile visualization depend on the data types, subject area, 3D printing hardware, and materials utilized, as well as the desired outcome in terms of educational goals and objectives.

Our first example demonstrates the approach to creation of tactile visualizations from a single 2D image. Here we used a high-resolution photograph of a micropolymer structure, taken with a camera mounted on top of an optical microscope (Fig. 2a). The photograph was processed and converted to a gray-scale image using Adobe Photoshop. Then a simple 3D polygon mesh was created in Autodesk Maya. This polygon mesh was further modified to allow the gray-scale image to fit and wrap appropriately to a surface while maintaining the accuracy of the gray-scale image and avoiding distortion during the transfer process. The gray-scale image was then mapped into a polygon mesh as a displacement map texture. Once the polygon mesh displacement was set, both elements were combined into a single-polygon model (Fig. 2b). The model was then analyzed and optimized further using MeshLab, before being imported to the Slicing software for 3D printing using the Makerbot Replicator 2, 4th generation printer. The final print (Fig. 2c) is 2 in. by 1.5 in. and is printed in white PLA with 100 μm resolution. This is a great example of a tactile visualization that can be used for visually impaired students. While normally they would not be able to see details in 2D image, they will be able to learn information about this complex structure encoded into rich surface topography.

The next example describes Biomedical 3D visualization that was created from 2.5D input (by 2.5 input we mean a collection of 2D images). In this scenario we started with a dataset of computer tomography (CT) images (axial, coronal, and sagittal Planes) of a human heart. The images were combined and processed in ImageJ and Kitware ParaView. Once the image stacks were

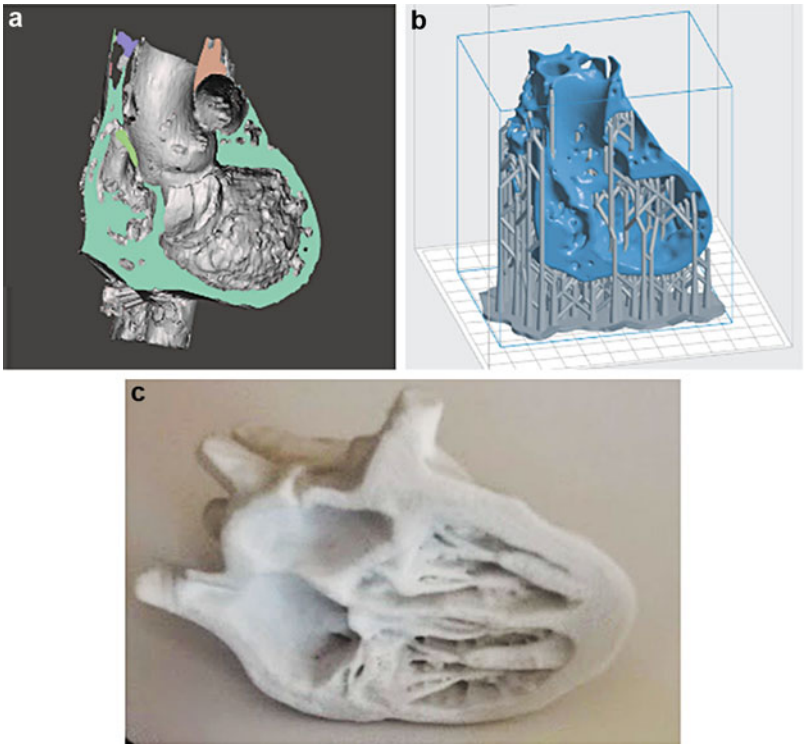


Tactile Visualization and 3D Printing for Education, Fig. 2 (**a**) High-resolution optical microscopy image, (**b**) embossed polygon surface, (**c**) 3D print (Pyayt and Kaplan University of South Florida

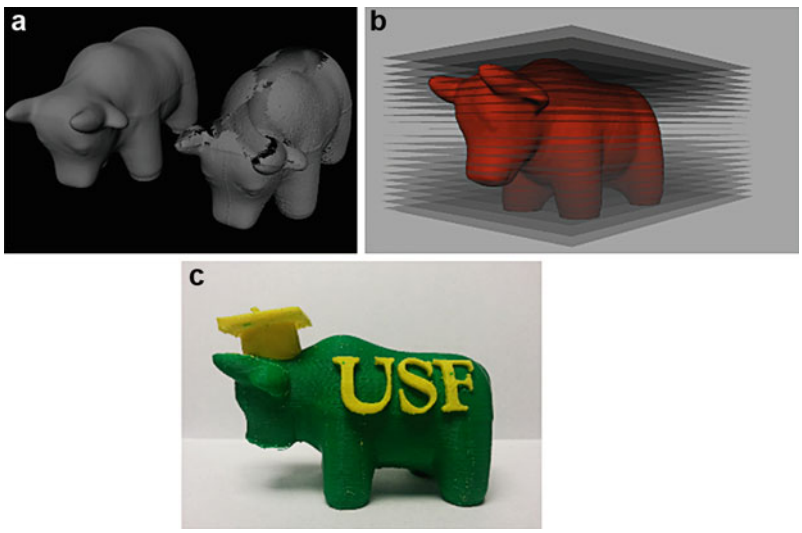
created, an appropriate threshold value was set for the selected areas. The selections were then used to generate volume renderings that were further analyzed, processed, converted to a three-dimensional polygonal surface, and exported as an.OBJ file. The.OBJ file was then imported to Autodesk Maya and MeshMixer for repairing and cleaning (Fig. 3a). The final model was sliced and printed on both the Makerbot Replicator 2, 4th generation, and Form1+ 3d printers (Fig. 3b). The final tactile visualizations were 3D printed using multiple materials including, PLA, ABD, dissolvable, and photopolymer resin (Fig. 3c). Biomedical students were directly involved in the creation of this visualization and as a result were able to build a better understanding of multidimensional data and medical image processing. Furthermore, the tactile visualization allowed the students to understand better the complex anatomical structure of a human heart.

Our final example demonstrates the use of both 2D image and 3D surface scan data as starting points for the generation of the 3D printing of tactile visualizations. Here we worked with computer science students to compare 3D surfaces generated from a 3D scanner to an algorithmically/programatically generated 3D surface created from two 2D images of a bull.

To build a 3D model from a 2D image, a custom program was written using OpenCV and OpenGL. The combined images generated a 3D polygonal mesh. The mesh was then repaired, processed, and sliced for 3D printing. The same bull that was photographed was also surfaced scanned using a NextEngine 3D Laser scanner. A point cloud was generated, cleaned, and then converted to a polygon mesh. The mesh was saved as an.OBJ file and then imported to MeshLab for further repair and processing. Once the model was ready for 3D printing, it was imported to the slicing software. Here, for both prints, we used KisSlicer. The settings and materials were also the same, as we wanted to conduct a direct comparison. Both models were printed several times on various printers; however, the initial models were printed on the FlashForge Creator Pro in ABS. These tasks allowed the computer science students to grasp not only multiple techniques for creating three-dimensional computer graphics but also the ability of tactile



Tactile Visualization and 3D Printing for Education, Fig. 3 (**a**) Surface reconstruction, (**b**) mesh in Form 1+ Software, (**c**) 3D print (Kaplan, Chittam, Das, University of South Florida)



Tactile Visualization and 3D Printing for Education, Fig. 4 (**a**) 3D triangulated surfaces, (**b**) Slice preview, (**c**) 3D Print (Kaplan, Pyayt, University of South Florida)

visualization in comparing and measuring the accuracy and detail through touch and physical rotation of 3D-printed models. The final result in comparing the models generated from an image and a 3D scan revealed that the scan was much more efficient and accurate in producing printable surfaces. However, even though it was expected, it was still a great educational experience, since the students learned a lot about different data input types (Fig. 4).

Conclusion and Discussion

Tactile visualization using 3D printing is an emerging area of research that examines how computer-supported, physical representations of data can enhance cognition, communication, learning, problem solving, and decision-making. Since tactile visualization is a new area, there is a lot of potential to develop it further and find new exciting applications.

Other interesting future directions include combining tactile visualization with a gesture control and tracking and touch-responsive and tangible user interfaces (TUIs) (Ishii 2008). They offer not just the ability to touch but also provide tangible force feedback and interactive audio output. Another approach is combining 3D printing, electronics, and microcontrollers, such as the open-source platform Arduino (Arduino 2015). The use of 3D-printed models and augmented reality displays might also be combined with data types to provide a more immersive experience for interactive data manipulation.

To summarize, tactile visualization combined with other new technologies can completely transform education and create new, more efficient, and enjoyable learning experience.

Cross-References

► Artistic Data Visualization in the Making

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Tangible Surface-Based Interactions

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Synonyms

Ambient-embedded interaction surfaces; Digitally encoded surfaces; Peripheral tangible interactions; Tangible surface-based interfaces

Definition

The surface-based interactions concept denotes a transparent spatial tracking approach for enhancing user interactions with physical objects and surrounding environments. It constitutes surface-based interaction models encapsulating multi-dimensional position and orientation tracking that enriches human-computer interfaces with augmented interactions and support for natural, self-explanatory components and semantics.

Introduction

In everyday life, people often refer to nearby objects by pointing gestures. In a shop, customers

point to products they want to buy, in a library to books they want to borrow, and in an office to documents they need. Such pointing or showing gestures are quite convenient and greatly facilitate communication between humans in a natural way. It is much different, however, when an automated system processes human requests. For example, at a self-service cash register, showing the goods to be purchased is not sufficient as each product must be appropriately oriented and placed in front of a barcode reader for scanning.

Being able to directly point anywhere on a physical object and get an identifier irrespectively of its position and orientation would be very useful. For this, instead of a single barcode, an encoding that covers the entire object surface could be applied (Kanev and Kimura 2005–2010, 2011). Similar to barcodes, a surface code applied to the object could return an object identifier for instant access to a repository where the price is stored (Kanev and Mirenkov 2010). In addition, information about the orientation of the object with respect to the scanner could also be extracted and employed, for example, for spatial queries (Bottoni et al. 2015).

Similar pointing functionality is used for interacting with screen-based representations of virtual reality (VR) models and nearby physical objects through VR and augmented reality (AR) applications (Xiao et al. 2018). High-quality AR integrates the virtual and physical components in a seamless way and ensures their synchronous presentation on the screen (Hamza-Lup and Rolland 2004). This, however, is a computationally expensive process that requires reliable recognition and simultaneous tracking of physical objects in real time (Wang et al. 2007; Nuchter 2009).

The surface-based interaction approach that we discuss in the following sections greatly reduces the computational burden since it facilitates the recognition and tracking of the physical objects by processing the digital codes on their surfaces (Kanev et al. 2007). In this way, instead of complex scene analysis and object recognition, just extracting and decoding the embedded digital information will suffice for the object identification and tracking (Kanev et al. 2008b).

Design and Implementation Summary

Let us consider some printed material such as a book and a surface code covering all of its pages. The surface coordinates of the book can be defined as page numbers followed by 2D positions on the page (Kanev and Mirenkov 2010; Signer and Norrie 2007). Such surface coordinates can be used for linking to multimedia content by invoking, for example, related hyperlinks (Barneva et al. 2009a). Global mapping of book coordinates to hyperlinks can be implemented through unique identifiers such as International Standard Book Number (ISBN) embedded in the surface code and distributed over the document surface.

Digital surface encoding can be applied to surfaces of physical objects by employing adhesive labels with preprinted digital codes (Kanev 2008). For direct digital encoding of object surfaces, physical engraving and laser marking can be used (Kanev et al. 2012b; Mizeikis and Kanev 2016). Objects with embedded surface encoding can also be produced by employing 3D printing and other manufacturing technologies (Kanev et al. 2015).

At larger scales, digital surface encoding can be employed for encoding walls of entire rooms (Saito et al. 2007; Kanev et al. 2012a). A mobile robot equipped with a digital camera and appropriate decoding software will then be able to precisely track its position and orientation with respect to the walls of such a digitally enhanced room (Barneva et al. 2013). Since position determination is based on extracting and decoding wall patches of limited sizes, it can be carried out even in cases of partially covered walls and objects obstructing the robot view (Kanev et al. 2010).

Specialized Surface Encodings

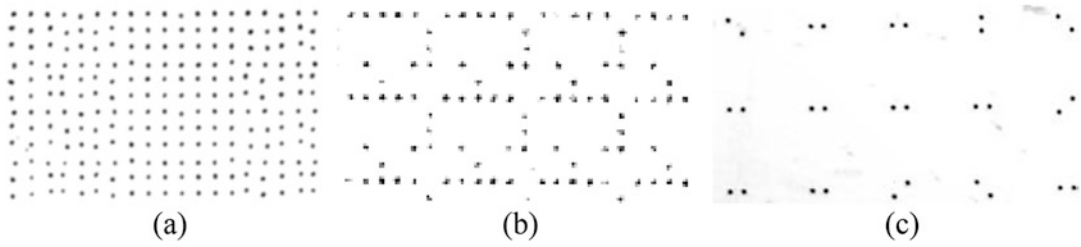
Uniform surface encoding with minimal ink coverage and sufficient redundancy for fast and reliable coordinate extraction requires codes with special properties (Barneva et al. 2009b; Kanev and Kimura 2006a; Pettersson and Ericson 2007). Such codes should allow for minimal alteration of

the encoded surface and the superimposed content (Fig. 1). In contrast to traditional barcodes, surface codes have no visible markers and block boundaries, thus encoding units must be identified by other means (Hecht 2001; Pettersson 2006).

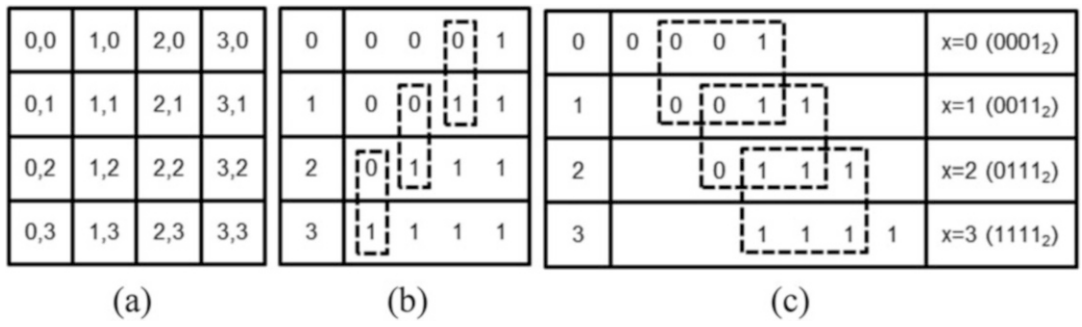
With respect to this, some theoretical issues of cluster pattern interfaces (CLUSPI) and related surface-encoding approaches are presented in Barneva et al. (2009b). The discussed CLUSPI codes are optimal in the sense that coordinates are encoded with a minimal possible number of bits, and since codes of adjacent coordinates differ by a single bit, code transparency can be significantly increased by the reuse of neighboring bits (Golomb et al. 1982; Kanev and Kimura 2011).

Using a Cartesian coordinate system, any rectangular surface area can be covered with a square grid and enumerated with two coordinates as shown in Fig. 2a. Each pair of integers denotes the x and y coordinates associated with the corresponding grid cell, e.g., (1, 2) stands for the coordinates $x = 1$ and $y = 2$. Depending on the desired area size, the employed coordinates can be confined to a specific range of integer values that can be binary encoded with a predetermined fixed number of bits. We can therefore define an *optimal coordinate code* that will differ by a single bit when encoding any two adjacent coordinates, as depicted by the dashed rectangles in Fig. 2b. Note that there is no room for further optimization, since any two adjacent coordinates are different so their encodings must also be different and therefore they must differ by at least one bit. When such an optimal code is employed for linear encoding, most of its bits may overlap so they can be reused as shown in Fig. 2c. In this way, we effectively encode each linear position by a single bit, while we can still use as many adjacent bits as necessary to construct a code of any size (Golomb et al. 1982; Kanev and Kimura 2011).

In Fig. 3, we show a sample bit sequence S that can be used for 9-bit coordinate encoding within

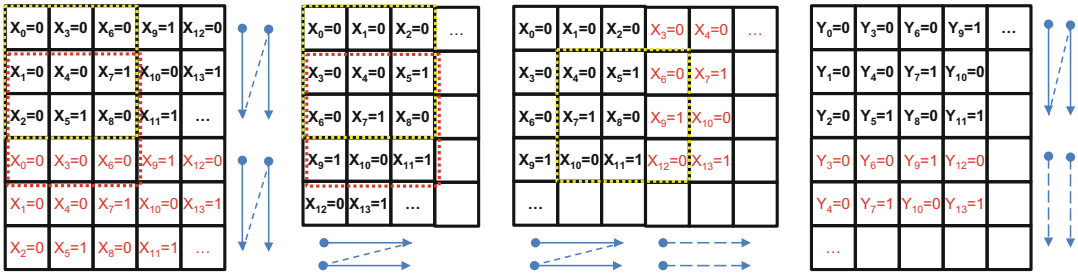


Tangible Surface-Based Interactions, Fig. 1 Specialized surface codes with no visible markers and block boundaries. Note the decreasing dot density from left to right (**a**–**c**) that improves the code transparency and thus helps reduce the visual impact on the overlaid content



Tangible Surface-Based Interactions, Fig. 2 Cartesian coordinates on a square grid (**a**), x-coordinate encoding of consecutive coordinates differing by a single bit (**b**), and x-coordinate bit overlapping and reuse (**c**)

Tangible Surface-Based Interactions, Fig. 3 The bit sequence S consisting of unique 9-bit subsequences. The red, highly elongated rectangle depicts a subsequence of 9 consecutive bits [63~71] that is suitable for coordinate decoding. The better-shaped blue rectangles, however, enclose subsequences of nonconsecutive bits that are not suitable for coordinate decoding



Tangible Surface-Based Interactions, Fig. 4 Area filling coordinate placement by ribbon folding in horizontal ((**a**) and (**d**)), and vertical ((**b**) and (**c**)) directions. The ribbon replication in y-direction (**a**) and the coordinate extensions in x-direction (**c**) and in y-direction (**d**) are shown in red

the range [0, 512]. The sequence S is constructed in such a way that any bit sequence of length 9 (except the sequence of 9 zero bits) appears exactly once as a subsequence of the sequence S. Therefore, any given 9-bit sequence could be associated with a unique offset determined by the position of its first bit in S. We will use the so defined offsets as coordinate values.

For proper coordinate decoding, we need to extract subsequences of 9 consecutive coordinate bits from the sequence S so we will seek surface bit placements that facilitate this process. The bit placement shown in Fig. 3 is clearly not quite suitable since the coordinate decoding would require imaging of highly elongated 1×9 rectangles (e.g., the red rectangle in Fig. 3) that significantly diverge from the typical camera views. Note that the better shaped rectangles shown in blue in Fig. 3 do not contain consecutive bits, e.g., [10~14, 73~77], [20~22, 83~85, 146~148], and [30~31, 93~94, 156~157, 219~220] for the rectangles from left to right.

If the coordinate bits are ribbon-folded as shown in Fig. 4a, however, some improvement can be achieved. Indeed, as depicted in Fig. 4a, the extracted bits are consecutive when the starting bit is on a row divisible by 3, e.g., the bits [0~8] in the yellow rectangle, but the bits will not be in order when the starting bit is on any other row, e.g., the bits [1~2, 0, 4~5, 3, 7~8, 6] in the red rectangle. In contrast, the ribbon-folding shown in Fig. 4b is free of the above defect as it always produces the coordinate bits in proper order, irrespectively of the position of the starting bit (compare the bit sequencing in the red rectangles in Fig. 4a which is not in order and in Fig. 4b which is in order).

The ribbon-folding in Fig. 4b might look contrary to the common sense, since our original intent was to encode the x-coordinate going from left to right, while in this ribbon-encoding, we went downwards and encoded a stripe in y-direction, leaving most of the surface to the right empty. Fortunately, it is easy to fix this by just extending the bit sequences from the stripe to

the right as shown in Fig. 4c. Now, with the entire surface overlaid with bit-encoded x-coordinates, it becomes clear that a sequence of 9 consecutive coordinate bits can be conveniently extracted starting at any surface position by examining a 3×3 square area, e.g., as shown by the yellow rectangle [4~12] in Fig. 4c.

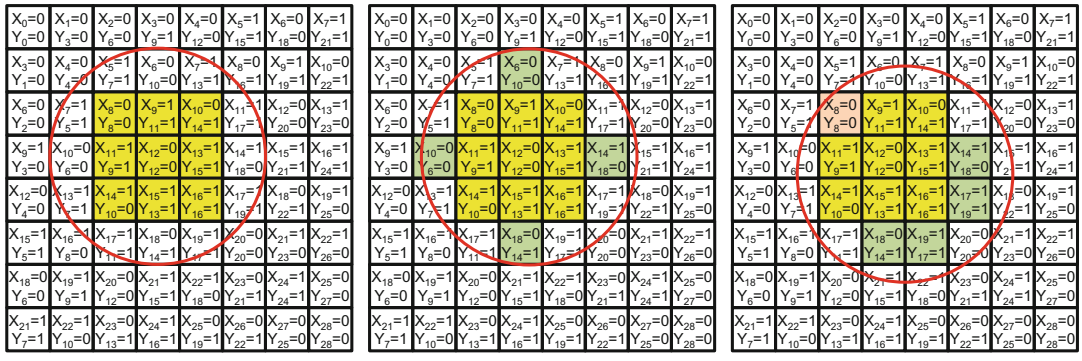
Note that the y-coordinates can be encoded in a much similar way. In this case, we start at the top left corner and fill the first three rows as shown in Fig. 4d. Then, we extend the bit sequences downwards, as depicted in red.

Our objective is to ensure reliable coordinate bit extraction and decoding irrespectively of the camera rotations related to the encoded surface. To account for this, in the following considerations, the typical camera view will be approximated by a sufficiently large circle, centered at the camera focal point as depicted in Fig. 5a. The diameter of the circle is set to five grid units despite that only 3×3 grid units would be required for the coordinate decoding. In this way, we ensure that a sufficient number of bits will be accessible for any displacement of the circle over the encoded surface.

When the camera view is centered in the middle of a grid cell as shown in Fig. 5a, a 3×3 cell area containing consecutive bits suitable for both x- and y-coordinate decoding can be extracted. When the camera view moves to the right, an additional grid cell comes into the view, e.g., (X_{14}, Y_{18}) in Fig. 5b. In a similar way, additional cells appear in the view when the camera moves into up (X_6, Y_{10}), down (X_{18}, Y_{14}), and left (X_{10}, Y_6) directions. When the camera moves diagonally, e.g., simultaneously down and to the right as shown in Fig. 5c, the cell (X_8, Y_8) disappears from the view, while four new cells, namely, (X_{18}, Y_{14}), (X_{19}, Y_{17}), (X_{17}, Y_{19}), and (X_{14}, Y_{18}) appear in the view. The obtained additional bits either overlap with some of the consecutive bits in the subsequence (e.g., X_{14} and Y_{10} in Fig. 5b) or can be used to extend the length of the subsequence (e.g., $X_{17} - X_{19}$ and $Y_{17} - Y_{19}$ in Fig. 5c).

Indeed, when moving the camera to the right at larger distances, some lower bits from the sequence will disappear from the view while other higher bits will instead appear in the view, which is consistent with the coordinate value increasing when moving to the right. Further on, as shown in Fig. 5, most of the peripheral bits that are close to the edges of the camera view are either replicated or replaceable by other higher or lower bits. This is consistent with the optical properties of the traditional camera input, where the highest quality view is obtained in the central area while most of the distortion is in the peripheral area.

To take advantage of the replica and substitution bits, we introduce *virtual blocks* that are



(a) (b) (c)

Tangible Surface-Based Interactions, Fig. 5 The camera is centered in the middle of a grid cell (**a**), moved to the right (**b**), and moved diagonally in right-downward direction (**c**). Yellow depicts the core cells, green the cells that enter the camera view, and red the cells that move out of the camera view

Tangible Surface-Based Interactions, Fig. 6 Virtual blocks of different shapes containing valid sequences of 9 bits for decoding of x-coordinates (**a**) and y-coordinates (**b**). In (**c**), the x-axis is shown in blue and the y-axis in red

defined as valid sequences of 9 consecutive bits irrespectively of their placement on the encoded surface, as shown in Fig. 6.

Note that these virtual blocks do not have any predetermined shapes, sizes, or placements, and that they can even overlap. The virtual blocks are just a way to access the coordinate encoding bits in an efficient and well-organized manner, while ensuring access to the necessary replica and substitute bits for corrections through redundancy and error recovery.

While we have placed all coordinate bits on a Cartesian coordinate system, the surface coordinates of our encoding are not necessarily Cartesian. Indeed, if we connect some starting positions that will decode to the same x-coordinate (X_7), as shown in Fig. 6c, we will obtain a line that is parallel to the y-axis. Doing the same for some starting positions that will decode to the same y-coordinate (Y_9), we can obtain the direction of the x-axis. Now it becomes clear that the encoded coordinates are given in a skewed coordinate system that is different from the initially chosen Cartesian coordinate system. The relationship between the decoded (X, Y) pairs and the corresponding row (R) and column (C) numbers is as follows:

$$X = C + 3^{*}R$$
$$Y = 3^{*}C + R$$

After solving for C and R, we obtain:

$$C = (3^{*}Y - X)/8$$
$$R = (3^{*}X - Y)/8$$

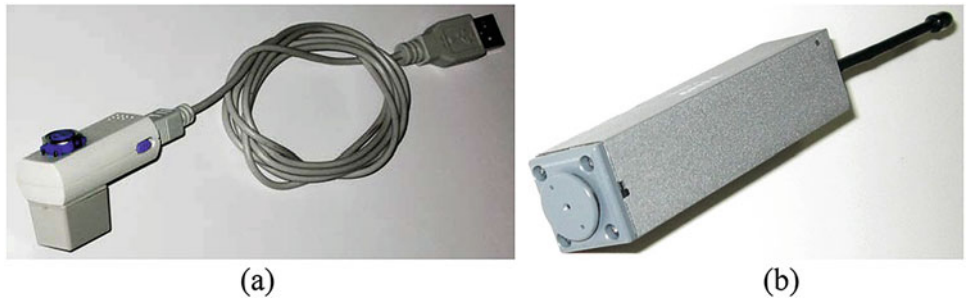
The above expressions allow for direct conversion of decoded (X, Y) coordinates to surface coordinates (R, C) expressed in row and column numbers.

Due to the above discussed special properties of the employed coordinate encoding bit sequences, no redundant encoding is required for recovering individual damaged or missing coordinate bits (Brimkov et al. 2020). Redundant encoding may be useful, however, in case multiple missing or damaged bits need to be recovered (Kanev and Kimura 2005–2010).

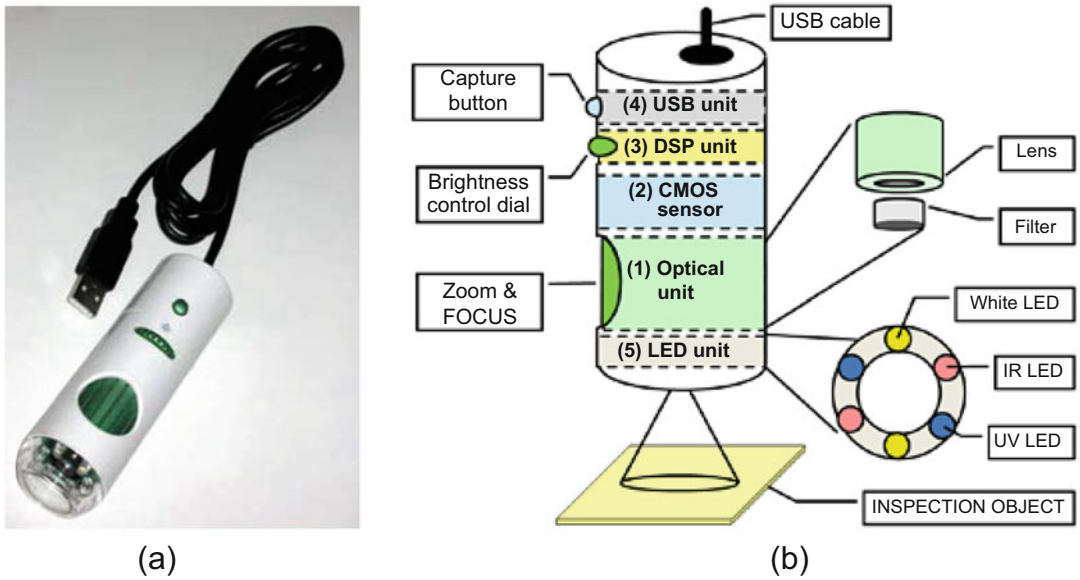
Applications and Implementation Examples

The direct-point-and-click functionality for printed materials (Kanev and Kimura 2006a) can be implemented through inexpensive handheld image acquisition devices. The compact surface code reader in Fig. 7a, for example, is based on a simple off-the-shelf Universal Serial Bus (USB) camera, while the device shown in Fig. 7b is based on a mobile wireless camera.

The more advanced optical code reader shown in Fig. 8a, on the other hand, functions as a digital microscope and supports the inspection of a wide range of surface under different magnifications



Tangible Surface-Based Interactions, Fig. 7 Optical code readers based on a simple off-the-shelf USB camera (**a**) and a mobile wireless camera employed as a surface code reader (**b**)

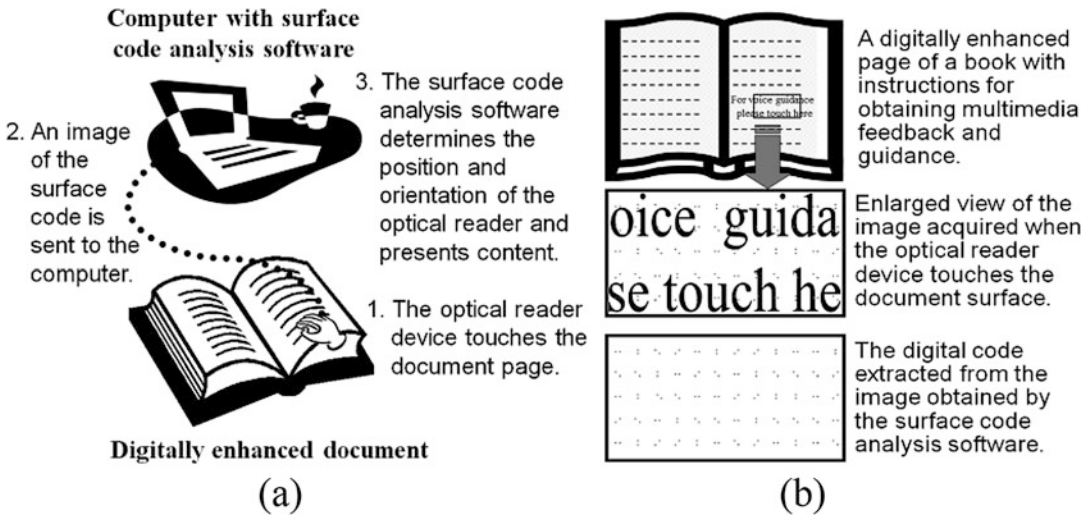


Tangible Surface-Based Interactions, Fig. 8 An advanced optical reader based on a digital microscope (**a**) with its structure and functional components depicted (**b**)

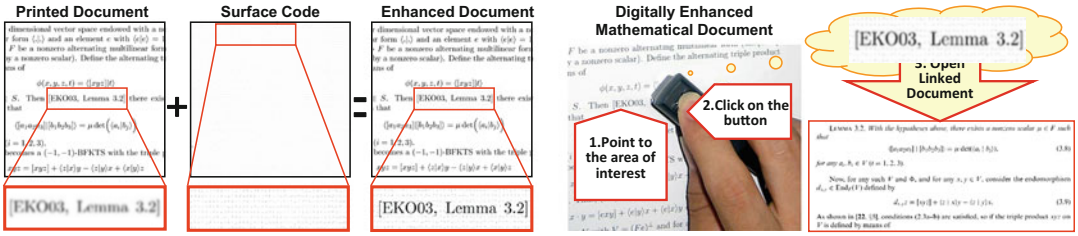
and light wavelengths (Kanev et al. 2008b). As shown in Fig. 8b, dial controls are provided for the brightness, and the zoom and the focus. The lighting unit on the front of the optical reader incorporates infrared, visible light, and ultraviolet LEDs, and accepts wavelength filter attachments for controlling the lighting conditions of the inspected surface.

Employing such surface code readers allows for interactions with digitally enhanced paper documents that provide more intelligent support for reading (Fig. 9) through instant access to linked digital content (Kanev and Orr 2006).

This approach is particularly suitable for mathematical documents where highly specific references are needed (Kanev et al. 2008a). As shown in Fig. 9, the reference embedded in the sample mathematical document denotes not only the source document (EKO03) but also a specific component in it (Lemma 3.2). Such references, embedded in mathematical documents, can be overlaid with surface encoded patches as shown in Fig. 10a and used for direct point-and-click access to the referred specific document components as shown in Fig. 10b.


Computer with surface code analysis software
2. An image of the surface code is sent to the computer.
3. The surface code analysis software determines the position and orientation of the optical reader and presents content.
1. The optical reader device touches the document page.
Digitally enhanced document
(a)
A digitally enhanced page of a book with instructions for obtaining multimedia feedback and guidance.
Enlarged view of the image acquired when the optical reader device touches the document surface.
The digital code extracted from the image obtained by the surface code analysis software.
(b)

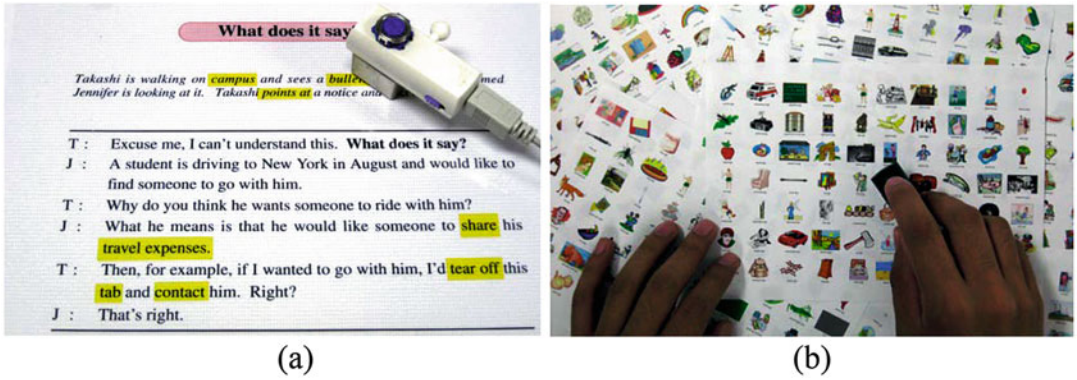
Tangible Surface-Based Interactions, Fig. 9 Interactions with digitally enhanced paper documents that provide more intelligent support for reading (**a**) and the enlarged views of the extracted images and digital codes that implement instant access to linked digital content (**b**)



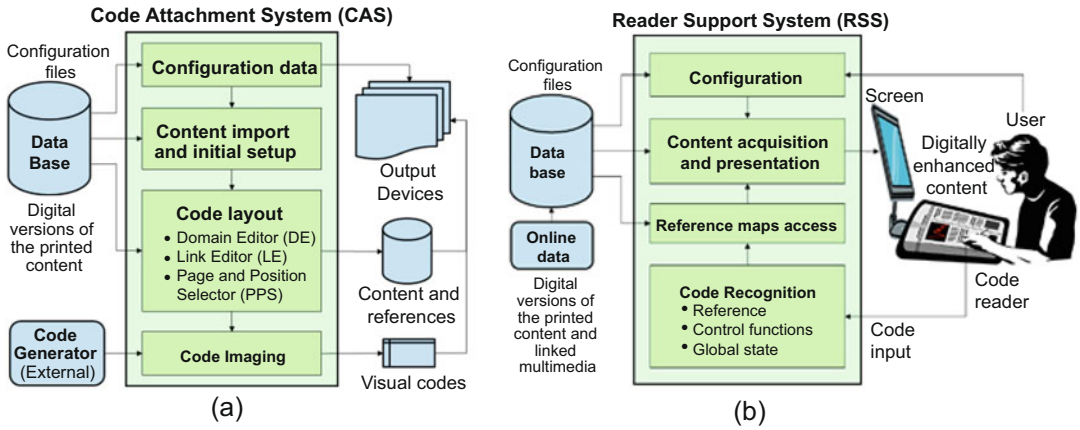
Tangible Surface-Based Interactions, Fig. 10 Digitally enhancing a highly specific reference (EKO03, Lemma 3.2) in a mathematical document (**a**) and employing an optical reader for direct interactions with the resulting digitally enhanced mathematical document (**b**)

Specific applications have been developed for language learning (Gelsomini et al. 2020), including sign languages (Kanev et al. 2009–2010). In Fig. 11a, we show some sample digitally enhanced printed content for Japanese learners of English. The point-and-click interactions with the content allow for pronunciation in native English and translation into Japanese of the highlighted words, as well as reading and translation of entire sentences. This approach has been extended to other languages by providing direct point-and-click access to a multimedia dictionary that supports a multiplicity of languages. In addition to the text-based point-and-click interface, the multilingual dictionary is also accessible through an image-based interface employing language neutral icons, as shown in Fig. 11b.

A more general approach for computer-assisted human interactions with the surrounding world that are based on ubiquitous surface encoding of physical entities and backgrounds has been discussed in Kanev and Mirenkov (2010). It introduces a more general concept that allows direct, real-time access to computer-based multimedia information through printed interfaces, which is further extended to active knowledge semantic surfaces for ubiquitous direct interaction environments with self-explanatory components. The implemented framework incorporates a code attachment system (CAS, Fig. 12a)


What does it say
T : Excuse me, I can't understand this. What does it say?
J : A student is driving to New York in August and would like to find someone to go with him.
T : Why do you think he wants someone to ride with him?
J : What he means is that he would like someone to share his travel expenses.
T : Then, for example, if I wanted to go with him, I'd tear off this tab and contact him. Right?
J : That's right.
(a)
(b)

Tangible Surface-Based Interactions, Fig. 11 A language learning support application for Japanese learners of English (**a**) and its extension to other languages through an image-based point-and-click interface with language neutral printed icons (**b**)



Tangible Surface-Based Interactions, Fig. 12 The code attachment system (**a**) and the reader support system (**b**) for digital enhancement of physical content and consequent direct interactions with it

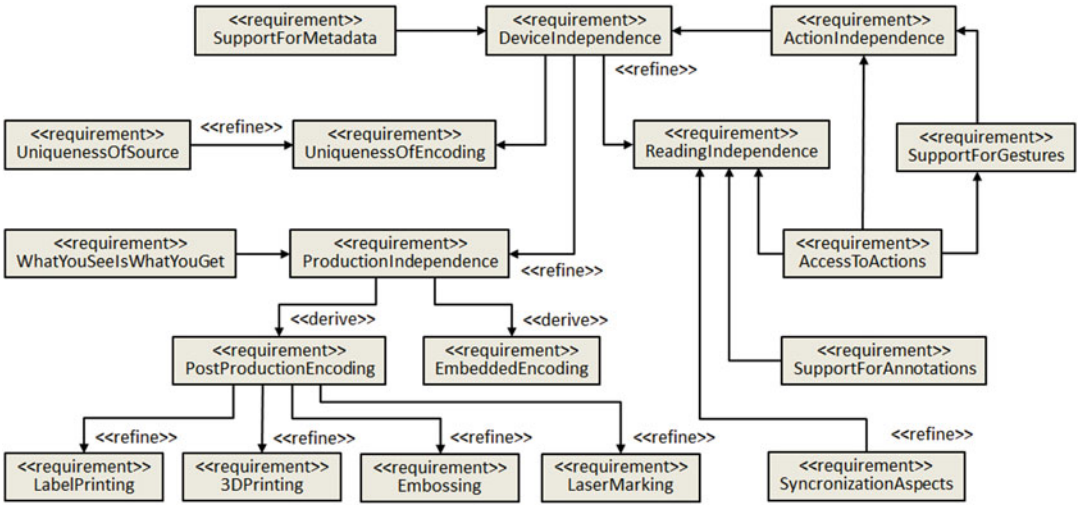
and a reader support system (RSS, Fig. 12b) that provide support for digital enhancement of arbitrary physical content and consecutive direct interactions with it.

The point-and-click functionality and the semantic surfaces concept have played an important role in the design and development of the more general framework for constructing collaborative surfaces through augmented documents and objects (Bottoni et al. 2013). More details about the employment of the framework for situated interactions expressed via UML profiles are provided in Bottoni et al. (2015). For illustration, a diagrammatic representation of relations among requirements for the augmented surface framework, supporting digital encoding of physical surfaces through traditional and 3D printing, embossing, and laser marking is shown in Fig. 13.

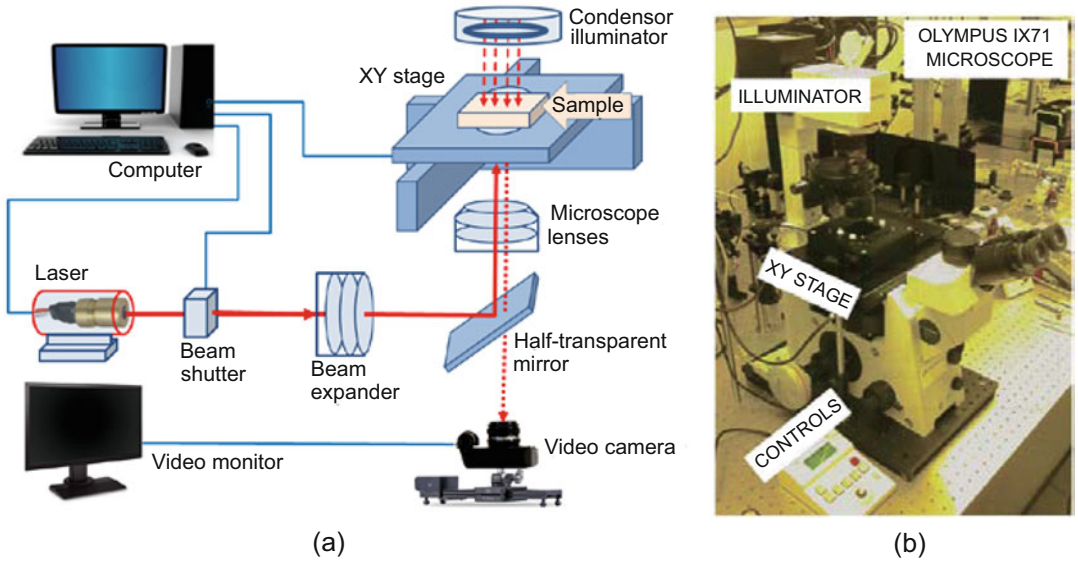
The framework for situated interactions has been extended to integrate the employment of physical objects as tangible interface components (Kanev 2012) and the concept of tangible technology enhanced learning (T-TEL) (Boytchev et al. 2012), and has been employed in later works related to technology enhanced collaborative surfaces for the next-generation classroom (Barneva et al. 2017). Based on this, applications for collaborative storytelling in T-TEL language

learning (Gelsomini et al. 2018a) and for Kanji learning in tangible AR settings (Gelsomini et al. 2018b) have been developed.

While surface encoding of physical objects is possible through printed labels, technologies such as laser marking (Gnatyuk et al. 2011; Diaci et al. 2011) allow for more robust and durable encodings. With respect to this, results of particular interest have been obtained for subsurface digital encoding of semitransparent substrates (Kanev et al. 2012b; Mizeikis and Kanev 2016). A schematic diagram of the experimental system for subsurface laser marking and a photo of the employed equipment are shown in Fig. 14.



Tangible Surface-Based Interactions, Fig. 13 Relations among requirements for an augmented surface framework supporting digital encoding of physical surfaces through traditional and 3D printing, embossing, and laser marking

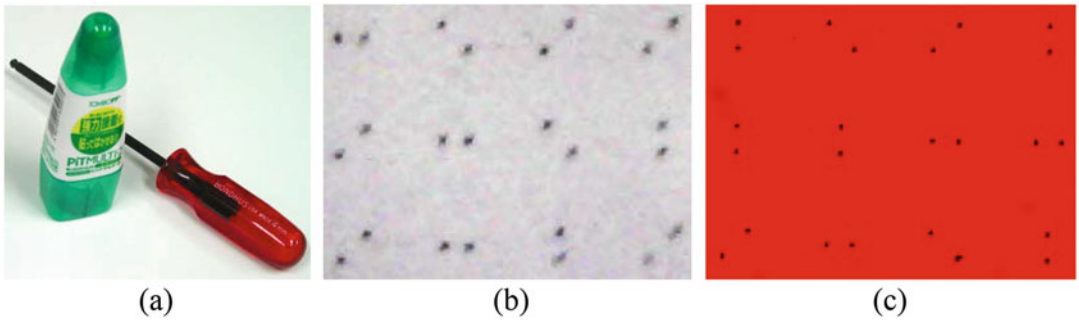


Tangible Surface-Based Interactions, Fig. 14 Schematic diagram of the experimental system for subsurface laser marking (**a**) and a photo of the employed equipment (**b**)

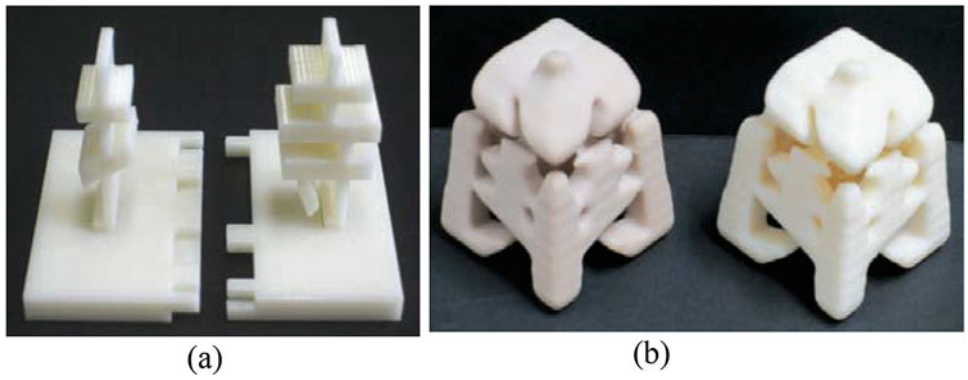
This system provides support for encoding of digital information in plastic objects using embedded bulk marking by tightly focused pulses of an infrared nanosecond laser. The marking consists of a machine-readable pattern of laser damage spots in the subsurface region of the object. Compared to surface marking by printing or laser ablation, this method presents the advantage of improved durability of the code. Some sample physical objects, digitally encoded through this method are shown in Fig. 15.

Instead of applying digital encoding to existing physical objects, in some cases, it may be desirable to incorporate the encoding into the object production process. As illustrated in Fig. 16, the 3D printing process allows for direct creation of such digitally encoded objects (Kanev et al. 2015).

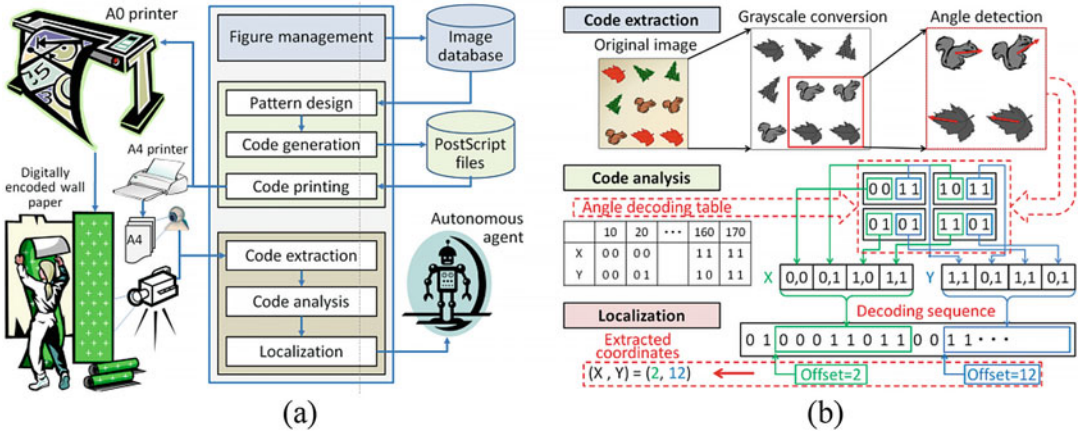
With respect to large-scale surface encoding, work has been done on surface-based spatial awareness for mobile robots (Kanev and Kimura 2006b), environmental codes for autonomous position determination (Kanev et al. 2012a; Barneva et al. 2013), encoding of surfaces for global positioning and navigation (Kanev et al. 2010), and more generally on direct-access pattern interfaces for geometric networks (Brimkov et al. 2016). In Fig. 17, we illustrate the production of digitally-encoded wallpaper for global positioning and navigation and the consecutive extraction and analysis of the embedded environmental codes.



Tangible Surface-Based Interactions, Fig. 15 Subsurface laser encoded plastic objects (**a**) and the corresponding code images obtained at infrared wavelength from the glue bottle (**b**) and at visible wavelength from the screwdriver handle (**c**)



Tangible Surface-Based Interactions, Fig. 16 2.5D (**a**) and 3D (**b**) kanji characters produced by a 3D printing process that allows for direct digital surface encoding



Tangible Surface-Based Interactions, Fig. 17 Production of digitally encoded wallpaper for global positioning and navigation (**a**) and consecutive extraction and analysis of embedded environmental codes (**b**)

Conclusions

While tangible surface-based interaction approaches may employ common methods for code processing and position determination, the actual surface encoding parameters depend on the specific application requirements. On the one hand, small objects observed from closer distances require fine encoding patterns that are practically invisible to the naked human eye. On the other hand, large-scale surface-encoded walls, and other interiors require aesthetic surface coverage that accommodates the necessary digitally encoded data without disturbing the appearance of the existing visual patterns. This was reflected in the wide spectrum of applications and related technologies for the physical embodiment of the surface codes covered hitherto.

Cross-References

- ▶ Foundations of Interaction in the Virtual Reality Medium
- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Interactive Augmented Reality to Support Education
- ▶ Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design
- ▶ Tracking Techniques in Augmented Reality for Handheld Interfaces

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Tangible Surface-Based Interfaces

► Tangible Surface-Based Interactions

Tank Controls

► Resident Evil 2, History of

Teaching Computer Graphics by Application

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Synonyms

Creating graphics; Graphics applications; Graphics for branding; Teaching graphics

Definition

Computer graphics classes teach the theory of making graphics and have students use existing graphics tools to make graphics. As an example, students in a computer graphics class learn about making graphics and products (letterhead, business card, brochure, website) with those graphics to create and express a brand.

Introduction

Computer graphics classes in the past revolved around the mathematics and programming for making tools that can be used to produce graphics and even had students write parts or components of software tools that make graphics. Today, the need has shifted to be good producers of the graphics content rather than the tools. Many graphics tools either require a sense of computer programming (e.g., Adobe Flash) or scripts, and small programs can be combined with graphics to create interactions in movies and games.

In this entry, what is currently included in computer graphics classes is reviewed, and a specific computer graphics class is described with example assignments from students at St. Mary's University in San Antonio, Texas (St. Mary's University 2015). The class has been taught over the last 6 years in the current format, about every year and a half from computer science department.

The St. Mary's class is for undergraduate and graduate students (graduate students do an additional research paper and presentation on a graphics-related topic) in the computer science degrees. The University offers undergraduate and graduate degrees in computer science and in computer information systems (CIS). This class, as many other computer graphics classes today, takes a CIS view of computers in business settings and applications, yet has the students learn how to use many graphics generation tools.

Computer Graphics Classes in General

Classes on computer graphics at high schools and community colleges usually emphasize how to make computer graphics, while 4-year and graduate programs tend to include or even focus on the theory of how computer graphics software programs work. Most of the computer graphics classes at the university level are offered from a computer science department and require a background in computer programming. University classes tend to include these topics in 2D and 3D graphics, as well as the mathematics behind some of these areas (Fedkiw 2015; Fussell et al. 2016; Schweitzer et al. 2010; Xiang and Plastock 2000):

- History of computer graphics
- Transformations
- Clipping
- Rasterizations
- Aliasing and anti-aliasing
- Projections
- Light, color, and shading
- Texturing
- Ray tracing
- Animation

Assignments in the classes range from mathematical problems within the graphics concepts to developing computer graphics products, usually from existing graphics tools. The tools most commonly used include OpenGL and the Adobe Creative Suite of tools such as Photoshop, Illustrator, and Flash.

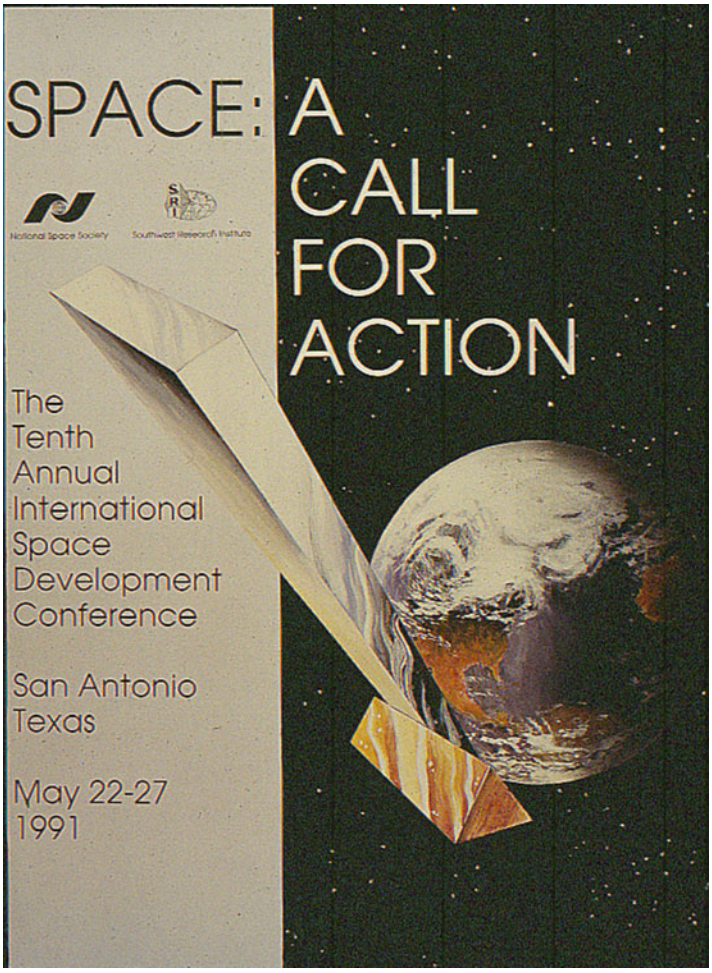
The following example class includes many of these topics and shows how they might be organized in a class; however, the focus is on producing graphics for an overall purpose of branding and marketing an organization or person, culminating in the graphics products used with a website that students create.

Computer Graphics Class Example Details

The computer graphics class is often taught in a hybrid format where the class meets physically together four times in the semester. The first meeting is at the very start to do an overview, review assignments, and define the expectations of the class. Small assignments are due each week during the first month or so. In the middle of the semester, the students show some of their products to the class. The last two classes are toward the end of the semester and have graduate students present their research and everyone to show their final product, a website with all the previous products included in it. The rest of the presentations, tutorials, and materials are on the Blackboard course management system, separated into weekly sections of articles, presentations, and links to review.

The class covers the following topics and encourages that students learn the tools given that are part of the Adobe Creative Suite tools:

- History of computer graphics
- What a brand is
- Design principles
- Making graphics:
  - Two dimensional (Microsoft Paint, Adobe Photoshop/Gimp) transformations, clipping, and aliasing/anti-aliasing
  - Animation (Adobe Flash/Blender)
  - Web development (Adobe Dreamweaver/Weebly)
  - Three dimensional [optional graphic product] (Cinema 4D/Maya/3D Studio Max/Lightwave 3D) light, color, shading, texturing, and ray tracing


SPACE: A CALL FOR ACTION
National Space Society
Southwest Research Institute
The Tenth Annual International Space Development Conference
San Antonio Texas
May 22-27 1991

Teaching Computer Graphics by Application, Fig. 1 Poster for ISDC 1991

Beyond the assignments of sending an email each week with things like what brands to evaluate and what topic to research, the students turn in the following assignments that are typically worth between 100 and 200 points:

- Evaluate and write about three existing brands
- Create and write up their own brand about an organization or company
- Make a logo in MS Paint
- Develop a suite of logos (in a better tool)
- Post their brand idea and logo in a discussion
- Comment on each other's brand and logo
- Create, print, and present a business card, stationary, and a brochure about their brand
- Make an animation with their logo about their brand
- Create and present a website about their organization or company using the graphics that they have made
- Research and present a topic (100 points), for graduate students only

Students often do research in the following areas: anti-aliasing, computational geometry, finite element methods in graphics, fractals, graphics in virtual environments, modeling natural phenomena, modeling nonrigid objects, molecular graphics, morphing, particle systems, radiosity, ray tracing, rendering, shadows, surface and light interactions, texture mapping, turbulence, and visualization.

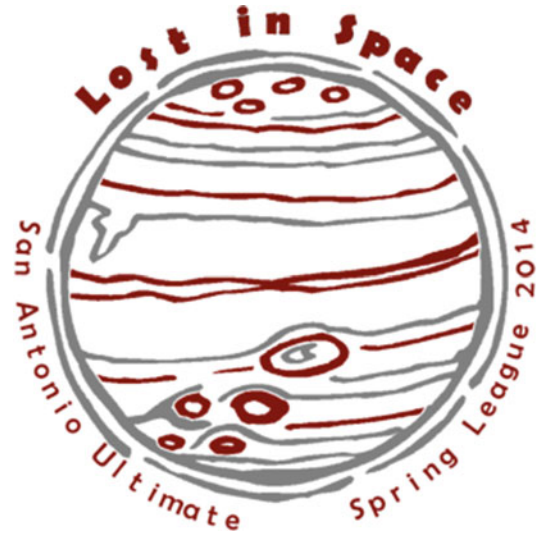
One of the assignments that makes this hybrid class unique and different is the posting of their

brand and putting a comment on every other student's brand and logo. In class, there would not be time for all students to make comments, and students might not make comments in the classroom.

Use Real Example Graphics

As part of the class, real graphics are shown that the professor made or had made for specific purposes. One of the main messages is to have a purpose for the graphics that are produced. For example, the International Space Development Conference of the National Space Society (www.NSS.org) in 1991 was chaired by the author. She worked with a graphic artist to develop an image that was used on posters, shirts, and brochures where the idea was to depict the Archimedes statement to give him a lever long enough and a place to stand and he could move the Earth. The conference theme was Space: A Call for Action. The conference was presented as the place to come find out about the actions large enough to get us moving and living off of the Earth. Figure 1 shows the resulting poster.

Many software development projects that included the development of graphics are presented such as an educational game called Dr Physio (Halff 2000) that taught middle school children better health behaviors including graphics for baboons, a lab, a savanna, basketball, food, scientists, a locker, a couch, exercise equipment, and a magazine. A recent example is from the San Antonio Ultimate Frisbee Leagues (SA Ultimate 2015) where a design is put on disks, bags, and shirts. That league is put on by a group of volunteers and the graphics are typically made by them. Figure 2 shows a design for a league from 2014 that had the theme of lost in space. The team names and colors were planets.



Teaching Computer Graphics by Application, Fig. 2 Ultimate Frisbee League design for lost in space

Student Example Graphics

Students have developed brands for all sorts of companies and organizations. Here are just a few of the ideas that they have developed:

- Book club
- Bookstore
- Brewing Beer
- Clothing sales
- Cloud services
- Coffee
- Computers
- Day care
- Family photos
- Flower shop
- Food:
  - Burgers
  - Dessert
  - Healthy
- Guard service
- Graphic design
- Help homeless
- Library
- Nuclear medicine
- Photography
- Resort
- Seaworld

Figure 3 shows many of the very creative business cards that have been developed by students that express their brand and include the logo that they made.

Teaching Computer Graphics by Application, Fig. 3 Student business cards

Teaching Computer Graphics by Application, Fig. 4 Handy Cloudware logos

As an example, one student developed a business he called Handy Cloudware. His name is Ken Handy, and he created a company to offer secure cloud solutions for businesses. His values were convenience, flexibility, simplicity, and safety. He first created the logos shown in Fig. 4, also showing the progression and improvement. Figure 5 shows a screen capture of his animation that showed the oval cloud spinning slowly between the hands. He used these graphics in his brochure and website for the company. He created some slogans and tag lines as well.

Teaching Computer Graphics by Application, Fig. 5 Handy Cloudware animation

Conclusion

The students who have completed this computer graphics class are from many walks of life and many cultures especially from the United States, India, and Saudi Arabia. Students from various backgrounds and cultures can learn to make computer graphics in a meaningful way to express their values in a brand that they create.

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Teaching Graphics

► Teaching Computer Graphics by Application

Technologies for the Design Review Process

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Synonyms

3D visualization; Design review process; Participation; Technology

Definitions

Design review is an overachieving work of the urban planning process. Pattern of user interaction is largely dictated by the urban planning technology rather than diversity and creativity of the users. Traditionally, urban planning technologies include substantial use of paper-based plans, maps, and text documents. Currently, urban planners rely on digital technologies, which lack mobility.

Introduction

Design review work is conducted by a diverse group of agents who belong to different socio-economic-political institutions, where each agent

is a contributing entrepreneur in the ecology of the urban planning enterprise (Forester 1989). There is now a wide array of immobilized, single-user digital media that could support information and 3D visualization needs of the design review process (Bellotti and Bly 1996). However, mobility is fundamental for visual perception (Gibson 1986). Specifically, the design review process requires mobility that supports spontaneous interaction and participation, exchange of useful information, local communication, and mutual awareness. Technology for this process should support self-explanatory operations without significant training through mutual intelligibility of individuals and technological interactions (Suchman 2007; Norman 2010). Yet, these aspects of the design review process are not supported by exiting technology that is tied to desktop computers and afford explicit communication (Bellotti and Bly 1996; Luff and Heath 1998). There is, however, an absence of intelligent and intelligible 3D visualization media that allows participatory communication and ubiquitous, interactive behavior. Having such media could reduce the time needed to examine development proposals within the design review process. This media may also result in the preparation of development proposals that does not require knowledge of Computer Aided Design (CAD), Planning Support System (PSS), and Geographic Information System (GIS). Furthermore, the proliferation of interactive surfaces and their chameleon-like quality have pervaded both the public and work environments, and in education and entertainment, however, the role of representational affordances and properties provided by such surfaces within the design review process is still largely unexplored (Rogers and Lindley 2004; Murray 2012; Vishkaie 2014).

This entry aims to provide a comprehensive understanding of the role current and emerging technologies play in the design review process. It synthesizes a literature review of academic research that investigates the subjects of the design review process and its engagement in digital technology.

Technologies for Participation and 3D Visualization

Role of Technology in Urban Planning

Computers have evolved from expensive, fragile, remote, and hard-to-use devices to inexpensive, small, easy-to-use, fast, and more powerful microcomputers. Furthermore, visualization in CAD, PSS, and GIS has taken advantage of the development of fast, high resolution, and full-colored display computers. Moreover, practice of urban planning has become more accessible with significant improvement in the capacity and speed of data storage and communication devices from Local Area Networks (LANs) to the Internet. In addition, this trend introduced the paradigm of "virtual organization" that enables information to be available to urban planners independent of their geographically dispersed locations (Norman 1993, 2010; Bellotti and Bly 1996; Kock 1999; Vishkaie 2014).

In the past, without computers, urban planners previously worked with paper-based documents such as spreadsheets and sketches, as well as crafted material. However, urban planners optimistically began using computers for urban planning and design purposes in the 1960s. In that period, computer-assisted planning was used in professional practice for large-scale metropolitan land use and transportation models integrated with municipal information. Consequently, the failure of these models in the 1970s demonstrated that the rationale of science for urban planning in creating such models was mostly inappropriate for public participation. Nonetheless, the development of microcomputers in the 1980s and the availability of GIS in the 1990s reignited urban planners' optimism in using computer aided planning (Norman 1993, 2010; Bellotti and Bly 1996; Vishkaie 2014).

Fundamentally, however, urban planners continually fail to use computers to perform urban planning functions in their professional practice. This problem originates primarily from the limited understanding of urban planning technologies by urban planners, which is a result from failing to

consider the human element. Additionally, the underlying rational for the design of a new urban planning technology that supports the current attitude in urban planning practice is to understand the particular needs of urban planners. However, focusing on a particular technology or an expert system that requires extensive technical training limits the introduction of a new urban planning technology (Norman 1993, 2010; Bellotti and Bly 1996; Vishkaie 2014).

The concept of PSS (see PSS section, below) suggests that the combined use of a different range of information technologies and models can enhance the specific professional responsibilities of urban planning. An interactive style of computer manipulation has been made possible with the use of electronic spreadsheets, database management systems, and graphical-multitasking operating systems. But, computers in urban planning are mainly used for general-purpose tasks such as office functions, processing documents, monitoring budgets, and maintaining records, thus, failing to take full advantage of the benefits of technological tools (Bellotti and Bly 1996).

In urban planning, stakeholders normally find it difficult to understand and digest technical actions, such as quantitative analysis. A solution to this is more technological advancement in urban planning. Moreover, visualization is also a valuable source of information that could assist communicative interaction by providing more visual thinking and understandable representation. Ultimately, urban planning's fundamental premise is to develop an understanding of solving problems through communication and collaboration among many participants (Forester 1989; Bellotti and Bly 1996).

In the 1960s, urban planning as an applied science suggests the fundamental transition of urban planning perception from design, which focuses on the traditional design of the physical city to an applied science, which is concerned with social science theories and quantitative techniques. In addition, the applied science model of urban planning describes information as a value and a politically neutral resource. This perspective requires that urban planners should provide useful information that informs and improves the policy-making processes (Bellotti and Bly 1996).

In the 1970s, urban planning as politics describes that information in urban planning which is not straightforward. Computer-based information and analytic techniques were used then in urban planning to transmit information from inaccurate paper-based record to a more accurate and current digital form. As a result, this led to increased public awareness surrounding the urban planning process as previously obscured issues began to be revealed and became one of the most important political implications of urban planning computer-based information systems (Bellotti and Bly 1996).

In the 1980s, urban planning as a communicative action describes urban planning as a collection of information for improving the policy-making process. Urban planning also involves formulating policy, making plans and revisions, negotiating, explaining, interpreting legal status, and undertaking quantitative analysis (Bellotti and Bly 1996).

Today urban planning, as a collective and communicative design process, suggests that urban planners' computer-based tools and technologies must support collaborative urban planning and collective decision-making processes. Currently, social and ethical views on urban planning communication focus on lower levels of abstraction on decision-making processes. These views suggest "collective common sense" and "deciding and acting" within an "interactive and inter-subjective communication" that follows the knowledge and consciousness of individuals (Norman 1993, 2010; Bellotti and Bly 1996; Vishkaie 2014).

Furthermore, the evolution of information technology has been critical to the organization and analysis of data, and ultimately, the creation of knowledge. This can be viewed as an evolving concern in urban planning that data changes into different forms of information within systems such as Urban Information System (UIS) and Land Information System (LIS). Information can support knowledge-based systems, which focus on analytical modeling capabilities such as Spatial Decision Support System (SDSS) (Bellotti and Bly 1996; Vishkaie 2014).

In the following sections, examples of applications that address the issues of urban planning and design review are discussed. CommunityViz and

CityEngine are selected to introduce these commercial applications as they are occasionally used throughout the urban planning and design process. URP is also selected to introduce a tangible system created for academic research that also supports the urban planning and design process (Vishkaie 2014).

CommunityViz

CommunityViz is a modeling and scenario evaluation planning and decision support system with visual and interactive components for community planning and design. This software is based on Esri's ArcView GIS that integrates words, numbers, maps, diagrams, and images in an interactive real-time and multidimensional environment. Furthermore, this multiagent simulation system integrates 2D mapping information, 3D visualization, and policy simulation technologies. CommunityViz is an open-ended process that allows users to test and evaluate the implications of plans for communities and for viewing existing and proposed buildings simultaneously (Walker and Daniels 2011; Vishkaie 2014).

Moreover, CommunityViz is composed of a series of integrated modules. Scenario Constructor works as the spatial component within the ArcView two-dimensional GIS framework. TownBuilder 3D displays 2D data in a 3D virtual world and receive instantaneous visual feedback in real-time. Policy Simulator is a multiagent simulation module that is designed based on complexity theory. Urban planners and designers, members of community, and elected officials are the audience for CommunityViz (Walker and Daniels 2011).

CityEngine

Esri CityEngine is a 3D modeling software that uses GIS for geo-design based on 2D and 3D data. Furthermore, CityEngine is used for 3D city modeling in a virtual urban and architectural environment, simulation, game development, and film production. It also provides tools to generate and modify buildings, layout and edit street networks, distribute street furniture, create 3D road profiles, control the shape of the skyline, and analyze urban planning projects and aggregate geospatial data. Moreover, CityEngine has features for sharing 3D city scenes, editing tools, texturing façade, generating reports, visualizing 3D zoning rules, and integrating with ArcGIS. In addition, urban planners and designers and architects are the audience for CityEngine (Esri 2017).

URP: A Luminous-Tangible Workbench for Urban Planning and Design

URP is an urban planning and design and architectural system for a physically based workbench setting. It further explores for facilitation, manipulation, exploration, and discussion how several variables relate to physical objects. Furthermore, it employs several luminous-tangible interactions to present visual information related to physical architectural objects. URP also aims at facilitating the constraints of future urban design and considers the existing architectural structures. In particular, URP focuses on visualizing measures of distance, shadows, and reflections at different times of day, as well as wind flow around buildings. Moreover, URP tends to focus on providing fluid and easy-to-understand manipulations to facilitate computation and thus the concrete realization of an abstract concept of the building plan. Urban planners and designers are the audience for URP (Underkoffler and Ishii 1998).

CommunityViz, CityEngine, and URP Critique

However, CommunityViz, CityEngine, and URP are cumbersome systems to operate. While both CommunityViz and CityEngine are integrated with ArcGIS, working with such software requires knowledge of GIS, which conflicts with the skillsets of urban planners or the public.

Furthermore, the limited adaptability and availability of URP as physical architectural structures to various design scenarios are some of the shortcomings pertaining to this system. Moreover, due to the complexity of the CommunityViz, CityEngine, and URP, these systems are not commonly used during negotiations between urban planners and developers, nor between urban planners and the public. In contrast, these discussions rely on more conventional tools, such as pen and paper. To some degree, tools such as pen and paper support visual and spatial thinking and explication that would enhance collaborative and

collective decision-making during the negotiation and discussion phases of the design review process.

Yet, it remains unanswered under what circumstances systems like CommunityViz and CityEngine would work well for facilitating communication and to what extent a system like URP could be applied in the practical circumstances of urban planning. Furthermore, what subtleties or nuances in the goals of these urban planning activities impact the design requirements for such tools?

Planning Support System (PSS)

Planning Support System (PSS) is a decision support tool that facilitates the preparation and evaluation of plans. PSS attempts to promote collaborative communication and interaction amongst urban planning stakeholders. Further, it allows urban planning stakeholders to visualize their future cities, also to provide a better understanding of their decisions. Furthermore, PSS uses analytic tools and computer simulation models along with visual displays to focus on urban and regional economic, demographic analysis and forecasting, environmental modeling, transportation planning, predicting future development, and land use patterns (Bellotti and Bly 1996).

Moreover, PSS is also a multidimensional application based on complex attributes such as mathematical theories and theories focusing on the structure and behavior of urban entities, urban planning processes, and spatial representations. As an information framework, PSS also tends to provide an interactive, integrative, and participatory information infrastructure for urban planning procedures. On the contrary, GIS is a fundamental component of the PSS, which requires spatial thinking skills and knowledge of GIS, thus, complex and challenging features of PSS may contradict with the skillset of urban planning stakeholders. Thus, PSS does not offer the ultimate solution to urban planning problems, and it seems unlikely to replace conventional tools and technologies in urban planning. CommunityViz and METROPILUS are both examples of planning support systems (Bellotti and Bly 1996).

Urban Planning and Visualization

The urban planning process involves extensive visualization of 2D digital maps and 3D digital models. New digital technologies such as CAD, PSS, and GIS are becoming available to support the visualizations needs of the urban design and planning process. However, there is a gap in characterizing the primary concerns of urban planning stakeholders' software skills and functions that urban planning software provides (Bellotti and Bly 1996).

In particular, design review is an iterative process that begins by first understanding the problem context through data collection and analysis to find possible design solutions. The design review process further attempts to implement alternative plans within parallel design and decision activities, which converge through government mandate or profitable solutions. In most cases, design solutions are defined in a cyclic fashion, which depends on mobilizing the knowledge and expertise of several diverse professionals involved in the process of design review. Additionally, in the design review process, plans and various stages of design and decision-making require communication between experts, professionals, and the public. The end results of these communicative and participatory activities are plans that visualize aesthetics, economic, social, and functional issues (Bellotti and Bly 1996).

Furthermore, there is a complex connection between urban design and planning and the socio-economic-political institution that ultimately impacts the appearance of cities. Oftentimes, decisions that are made within socio-economic-political processes tend to address the consistency between land use, transportation, and air quality conflict with the analytical methods of urban design and planning. For example, transportation planning attempts to reduce congestion through a decrease in carbon dioxide (CO_2) emissions. Thus, to enhance the stakeholders' comprehension, the socio-economic-political implications of urban design and planning actions

should be accessible in visual formats (Bellotti and Bly 1996).

Specifically, the development of new digital technologies has moved visualization to be one of the most important activities in the urban planning and design process. For example, visualization technology for the urban planning and design process can help in problem-solving, evaluating plans, and presenting spatial information that informs analysis, prediction, and optimization. Recently, decision-making systems have been combined with Virtual Reality (VR), Cave Automatic Virtual Environment (CAVE), and holobench. These tools combine CAD, GIS, and multimedia or 3D GIS tools that include all of the functionality of 2D GIS. However, today, there is no evidence that CAVE is commonly being used by municipalities (Bellotti and Bly 1996).

Moreover, most of the current urban planning digital technologies focus on forward visualization that involves developing visual tools to support the public and interested groups. Yet, there are specific digital technologies developed for backward visualization that involves developing visual tools to support experts and professionals. However, absent is the presence of a visualization aid that specifically supports the value and significance of communication and participation in the design review process deliberation. As opposed to the current trend, such a visualization aid should avoid the separation of target users, depending on their level of expertise. Creating a balance between the needs of users would allow for integration of the workflow of urban planning stakeholders from naïve to expert, to address their challenges in a participatory manner (Bellotti and Bly 1996; Norman 2010).

Groupware and Computer-Supported Cooperative Work in Urban Planning

Urban planning has recently been involved with computer-supported techniques that try to maximize collaboration. These techniques include groupware, Computer-Supported Cooperative Work (CSCW), and cooperative and participatory design. Furthermore, "Groupware is an umbrella term for the technologies that support person-to-person collaboration; groupware can be anything from email to electronic meeting systems to workflow." Groupware also includes shared drawing, group decision support, and scheduling and project management. As well, groupware allows urban planning activities within groups to negotiate spatially while designing plans and sketches and writing documents (Laurini 2001).

In addition, to enhance work efficiency in the design review process, three important elements should be considered. First is agile communication and interaction, which aims at sharing information amongst urban planning stakeholders to negotiate possibilities and solve conflicts. Second is good information, which concentrates on cross-referencing submitted building proposals against bylaws and regulations. Third is effective processing and visualizing tools, which aim at providing spatial data handling tools and office automation functions (Jie et al. 2000).

Integration of these elements with groupware communication and interaction could be a useful mechanism to increase efficiency in the process of design review. For example, by having access to the Internet, groupware provides more opportunities for urban planning and design processes. This involves participation, increased productivity, fewer meetings, automating routine procedures, and the integration of geographically disparate teams. However, groupware involves limitations such as a lack of training and education for practitioners and the business community. The virtual workbench and virtual reality systems such as virtual cities are examples of a groupware setting (Laurini 2001).

Role of Interactive Surfaces in the Design Review Process

Digital media that would enhance visualization should be characterized by unpacking the ethical, communicative, and participatory challenges embedded within the socio-economic-political institution of the design review process. This issue should be characterized by the relationship between users from expert to naïve and technologies from old to new. Recognition of these challenges could lead to an attempt to reconcile

pluralistic values in the design of a new generation of a communication medium for the design review process using interactive digital media. There is a growing corpus of academic and industry work on this topic, however, there is a gap in the characterization of many aspects that would enhance the significance of visualization, communication, and equal participation in deliberation tied to the use of interactive surfaces (Forester 1987, 1989; O'Doherty and Einsiedel 2012; Vishkaie 2014).

Specifically, from a socio-technical point of view, the design review process is not adequately understood. In the design review process, technical and political conversations are media for making sense together. Communication throughout the design review process is a guiding instrument for back and forth and the iterative process of design. The design review process involves the participation of various individuals such as architects, developers, urban planners and politicians, who sketch, present, and modify ideas and concepts, also to review the paper and text-based bylaws and regulations. Furthermore, the design review process yet relies on the culture and use of traditional and somewhat inefficient tools and technologies (Forester 1987, 1989; Vishkaie 2014).

Examination of the design review process reveals that mobility is critical to the participatory work of urban planners. Mobility could possibly enhance tasks and responsibilities of urban planners. Local mobility that is a fundamental element to access individuals and shared resources is also essential to the design review process. Technology that supports local mobility would ease the informal and participatory interaction and awareness within the design review process. However, the requirements to support mobility in the participatory process of the design review have received little attention (Bellotti and Bly 1996; Scott et al. 2003).

In particular, "micro-mobility" refers to mobilizing and manipulating artifacts within the organizational setting, where various activities occur. Studying the design review process shows the "micro-mobility" of tools and technologies is critical to the work and communication amongst urban planning stakeholders. It is widely recognized that the access to real-time information, and the need for immediate collaboration with others, are essential parts of the design review process. However, the design review process still depends highly on the use of traditional paper and text-based documents (Luff and Heath 1998).

Exploring the design review process provides another lens of understanding about how the complexities of computer aided planning have not been featured in empirical studies of the communication and participation activities within the design review process. What has not been identified is that computer aided planning systems are currently bound to inflexible desktop workstations, whereas all urban planning stakeholders do not have access to the technological tools to participate in communication and design processes. In addition, typical single-user urban planning desktop computer applications do not support participatory and multiuser interactions required within the design review process (Luff and Heath 1998; Scott et al. 2003).

Moreover, participation that is a sensitive part of the socio-economic-political context of the design review process has been impacted by the traditional trend that has kept computer aided planning routinely at stationery workstations that have become increasingly complex. Group feedback has also been largely neglected by the limited movement of individuals who are still tied to complex and inflexible technologies. In exploring different stages of the design review process, the mobility of urban planning stakeholders, information, documents, and artifacts is considered fundamental in enhancing participation and communication (Luff and Heath 1998; Tufte and Mefalopulos 2009; Vishkaie 2014).

In the absence of a technology that provides a platform for generating a shared understanding through visualization, the manipulation of conversation occurs. As a result, urban planning stakeholders could interpret basic parameters differently. Thus, it can be argued that the process of participatory design and communication of the design review is significantly tied to the role of fixed technologies that are not easily accessible to all stakeholders. These fixed technologies are not

self-evident, thus they require a certain level of knowledge and expertise to perform urban planning work. Therefore, the prolonged process of the design review, a lack of knowledge of design and perspective, and insufficient comprehension are the results of inaccessible and inefficient exiting urban planning technologies, wherever the urban planning stakeholders attempt to participate and communicate (Forester 1987, 1989; Bellotti and Bly 1996; Vishkaie 2014).

The adaptation of fixed interactive surfaces to traditional desktop computers has recently become a concern to the research and industry communities. Such surfaces are becoming important tools for solving problems in urban planning. For example, the research community has explored that interactive surfaces are used for the planning and designing neighborhood (Fernquist 2010). The research community has also investigated the design of a collaborative PSS for use on a multitouch tabletop (Su 2011). Furthermore, an urban planning, nonimmersive virtual environment is designed for spatial analysis (Vandoren et al. 2005).

In addition, Mixed Reality (MR) that is used for a bimanual handheld urban planning interface supports searching, inserting, and creating contents (Sareika and Schmalstieg 2010). The Urban Sketcher is also designed to improve real-time communication amongst urban planning stakeholders (Sareika and Schmalstieg 2007). Further, augmented and mixed reality and interactive tangible tabletop and 3D printed models of buildings are used to improve participation in urban planning through the communication of digital models (Välkkynen et al. 2013). On a commercial level, CommunityViz, in combination with fixed interactive surfaces, provides regional information through the collective use of digital maps (Placeways 2017).

Discussion

Although this entry does not tend to propose an optimistic scenario of new media for the design review process, the cultural technologies of digital media imply user empowerment through enhancing individual liberty and social harmony. All of the arguments deemed above may further suggest directions for designing a mobile communications technology for the design review process to access geo-located and real-time information while on the move. This mobile communication technology could increase mobility and create a balanced communicative and participatory relationship between urban planning stakeholders by reaching a wide audience. The combination of mobile with fixed interactive surfaces would support the different forms of participation required for the design review process. This system should also have a limited amount of textual and diagrammatic documents, and instead have more graphical tools to clearly visualize ideas and concepts (Norman 1993, 2010; Murray 2012; Vishkaie 2014).

In a nutshell, traditional urban planning technologies highlight several shortcomings and challenges that require the consideration of complex accounts to be ameliorated. Although the use of interactive surfaces is not naïvely overrated, the purpose of this entry is to capture reflections on the complexities and challenges of thinking through improving visualization, communication, and participation as fundamental components of the design review process in the governance of new digital media genre (Norman 1993, 2010; Murray 2012; Vishkaie 2014).

Conclusion

Computer aided design, a planning support system, and a geographic information system are current technologies used in the urban planning process. Adaptation of interactive surfaces to the CAD, PSS, and GIS will be an avant-garde technological development in computer aided planning and other related fields. Previously, the affordances and properties of technologies that run on desktop computer applications have reduced draftsmen's needs for manual drafting and drawing. This then facilitated designers and engineers in pursuing their individual analytic, drafting, and drawing goals, although somewhat in isolation. Similar to the beginning of CAD creation, the adaptation of interactive surfaces to

CAD, PSS, and GIS is the next step in technological advancement, thus these developments will shorten the design cycle and lessen the associated design costs. To sum up, these changes foreshadow that an era of manual, somewhat inefficient, and inaccurate computation; 3D visualization vagueness; and interaction exclusively on single desktop interface metaphor is the way of the past. In the future generation of computer aided planning, and in a broader context of computer aided technology, knowledge and skill will not be the prerogative to experts and professionals. Instead, individuals with limited software skills will also be able to engage in the participatory design review process via the introduction of interactive communication media. Hence, the integration of interactive surfaces with easy-to-use technologies carries the potential to be in the forefront of the design a new genre of digital media for the design review process. In fact, this is the way of the future (Vishkaie 2014).

Considering these aspects, this entry shows how the study of technology within the design review process can provide rich insights into the individual and shared experiences that evolve around such digital media. These insights can guide the innovation and creation of user-centered designs for computer aided systems beyond limited capacities of the current CAD, PSS, and GIS (Vishkaie 2014).

Cross-References

- ▶ 3D Visualization Interface for Temporal Analysis of Social Media
- ▶ Exploring Innovative Technology: 2D Image Based Animation with the iPad
- ▶ Interaction with Mobile Augmented Reality Environments
- ▶ Interactive Virtual Reality Navigation Using Cave Automatic Virtual Environment Technology

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Technology

▶ Technologies for the Design Review Process

Telepresence

▶ Life-Size Telepresence and Technologies
▶ Presence and Immersion in Virtual Reality

Tensor Field Visualization

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Definition

A tensor, specifically a second order tensor, is a linear mapping from vectors to vectors and is represented by a multidimensional array of values called its "components."

A tensor field is a mapping from each point in some spatial domain (usually 2D or 3D) to a tensor.

Tensor field visualization is the process of visually representing tensor fields so that features of interest in the field become apparent to the viewer.

Introduction

Some physical phenomena can be represented by a single number, or *scalar* value. Temperature and density are well-known examples. Other quantities characterized by a magnitude and direction, like force and velocity, are represented as a *vector*. Yet other phenomena, like mechanical stress and diffusion, are represented by a *matrix*. This progression, from scalar to vector to matrix, is generalized by the concept of tensor order. Tensors of order 0 are represented by scalars, tensors of order 1 are represented by vectors, and tensors of order 2 are represented by matrices. The order of a tensor can be thought of as the number of indices required to uniquely identify the components of the tensor. In d dimensions a tensor of order n has d^n components. Using subscript notation a second-order tensor is written as $\boldsymbol{D}_{ij}$ where each of the indices, i and j, can have d possible values.

In general, tensors may have two different types of indices, covariant and contravariant. These are differentiated by using subscripts for covariant indices and superscripts for contravariant indices. For tensors in Euclidean space (i.e., Cartesian tensors) the two types of indices are equivalent, so only subscripts are used. In this work we concentrate on Cartesian tensors in 3D ($d = 3$).

A *tensor field,* $\boldsymbol{D}(\boldsymbol{p})$, is a mapping which assigns a tensor, $\boldsymbol{D}$ to each point, $\boldsymbol{p}$, in a spatial domain. Analogously we can define *scalar fields* as mappings from points to scalar values, and *vector fields* as mappings from points to vectors.

Second-order tensors are often analyzed and described in terms of the properties of the matrices that represent them. Symmetry implies that the tensor does not change when the order of indices

is changed, $\boldsymbol{D}_{ij} = \boldsymbol{D}_{ji}$. In 3D ($d = 3$) the symmetric second-order tensor,

$$\boldsymbol{D} = \begin{bmatrix} D_{xx} D_{xy} D_{xz} \\ D_{xy} D_{yy} D_{yz} \\ D_{xz} D_{yx} D_{zz} \end{bmatrix} \quad (1)$$

has six unique components: D_{xx}, D_{xy}, D_{xz}, D_{yy}, D_{yz}, D_{zz}.

The eigenvalues and eigenvectors of a matrix are defined by the relation

$$\boldsymbol{D}\mathbf{v} = \lambda \mathbf{v}. \quad (2)$$

The scalar values, λ, and vectors, $\mathbf{v}$, that satisfy this relation are called the eigenvalues and eigenvectors, respectively, of the matrix $\boldsymbol{D}$. It is difficult to give a general intuition for the meaning behind the eigenvalues and eigenvectors of a matrix, but they provide a simplified representation of the linear transformation represented by a matrix. For some special cases of matrices, there are known properties of eigenvalues and eigenvectors.

- Real-valued symmetric matrices have mutually orthogonal eigenvectors and real-valued eigenvalues.
- Positive-definite matrices (such that $\boldsymbol{x}^T \boldsymbol{D}\boldsymbol{x} > 0$ for all $\boldsymbol{x}$) have positive eigenvalues.

It is common to sort the eigenvalues from largest to smallest absolute value, and index the eigenvalues and corresponding eigenvector by this sorted order such that $|\lambda_1| \geq |\lambda_2| \geq ... |\lambda_d|$. In this notation the eigenvector corresponding to λ_i is $\mathbf{v}_i$.

Applications

In engineering and science, most tensor field visualization applications involve symmetric second-order tensors, which are the main focus of this work. Some physical processes which involve tensor quantities are molecular diffusion in liquids, which has implications in medical imaging, and mechanical stress and strain. In mathematics, tensors are used to describe the differential geometry of manifolds. Asymmetric tensors arise when the gradient of a vector field is computed. For example, the gradient of a velocity field is used in the study of fluid mechanics, and the gradient of a deformation field is useful in solid mechanics analyses.

Diffusion

Brownian motion is the random molecular motion which leads to water transport at a microscopic scale within living organisms. The structure of the surrounding tissue can influence the diffusion process, sometimes making it directionally dependent (or *anisotropic*). In Gaussian diffusion, the directional dependence is characterized by a symmetric, positive-definite second-order tensor known as the "diffusion tensor." It can be computed in terms of the covariance matrix of the normal distribution which describes molecular displacement probabilities.

Within an oriented structure, such as the white matter of the brain which consists of bundles of parallel neuronal fibers, the principal diffusion direction (PDD) tends to be parallel to the fiber direction. Magnetic resonance imaging (MRI) protocols have been developed which permit the diffusion tensor to be estimated. The diffusion tensor can be used to infer tissue structure at the millimeter scale and describe the directional dependence of diffusion. The PDD is given by the eigenvector $\mathbf{v}_1$ of the diffusion tensor.

In the 1990s, diffusion tensor MRI (DT-MRI) (Basser et al. 1994) enabled white matter structure to be indirectly assessed by estimating the attenuation of the MRI signal due to diffusion of water molecules. More recently, the imaging technique has been refined using more general models of the diffusion process, including non-Gaussian diffusion characterized by tensors with order greater than 2. This has resulted in improved fiber tractography techniques and enabled more precise assessment of anatomical connectivity in the brain. Visualizing tensor fields in this context can lead to improved understanding of brain architecture and permit clinicians to make diagnoses on the basis of DT-MRI.

Tensor Field Visualization, Fig. 1 Ellipsoid glyphs

Stress and Strain

When external forces are applied to a material, internal stresses are produced which lead to deformation, also known as strain. The second-order strain tensor $\boldsymbol{\epsilon}_{ij}$ represents the changes in shape of a material under stress. The second-order stress tensor, $\boldsymbol{\sigma}_{ij}$, provides a complete description of stress at a point. Given an axis-aligned infinitesimal cube, the index i represents force components, and index j represents the components of the normal to the surface on which the force acts. So, for example, the component $\boldsymbol{\sigma}_{xy}$ is the force in the +x-direction acting on the +y-face of the cube. Conservation of angular momentum dictates that the stress tensor is symmetric. Unlike the diffusion tensor, the stress tensor is not necessarily positive definite. It may have negative eigenvalues, such as when compressive external forces are applied to a solid. Visualization of stress tensors can assist engineers in the design and analysis of structures.

Glyphs

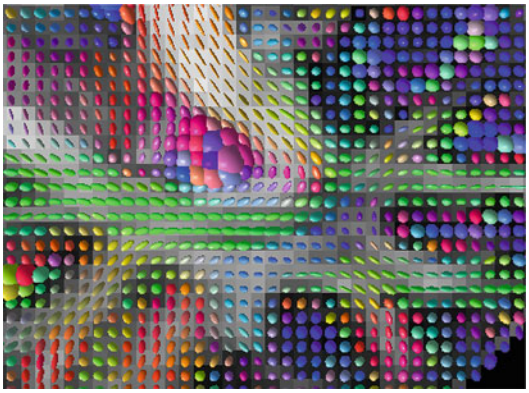
Glyph-based visualization techniques display a small graphical icon at each point in a domain to represent a tensor. One of the most commonly used tensor glyphs is an **ellipsoid** computed by transforming the 3D vertices, $\mathbf{p}$, of a triangulated sphere by the tensor, $\boldsymbol{D}$ yielding transformed vertices

$$\mathbf{q} = \boldsymbol{D}\mathbf{p}. \tag{3}$$

Ellipsoids for the tensors

$$\boldsymbol{D}_1 = \begin{bmatrix} 3\,0\,0 \\ 0\,1\,0 \\ 0\,0\,1 \end{bmatrix}, \boldsymbol{D}_2 = \begin{bmatrix} 2\,-1\,0 \\ -1\,2\,0 \\ 0\,0\,1 \end{bmatrix}, \boldsymbol{D}_3 = \begin{bmatrix} 1\,0\,0 \\ 0\,1\,0 \\ 0\,0\,1 \end{bmatrix} \tag{4}$$

are shown in Fig. 1.



Tensor Field Visualization, Fig. 2 Detail of ellipsoidal glyphs computed from DT-MRI of the human brain

This glyph gives a visual representation of the tensor that can be understood in terms of the eigenvalues and eigenvectors of the tensor without requiring them to be explicitly computed. The major and minor radii of the ellipse are given by the eigenvalues of the tensor. The major axis of the ellipse is given by the eigenvector corresponding to the maximum eigenvalue of the tensor, λ_1. In diffusion applications the major axis is known as the principal diffusion direction (PDD), the direction in which diffusivity is highest. Diffusion ellipsoids for a slice of DT-MRI data are shown in Fig. 2. For a stress tensor the major axis of the ellipse corresponds to the major principal stress axis.

For symmetric tensors in 3D there are three characteristic ellipsoid glyph shapes that emerge, depending on the relative magnitudes of the three eigenvalues.

- Linear "cigar" shapes elongated along one direction, $\lambda_1 \gg \lambda_2 \approx \lambda_3$
- Planar "pancake" shapes flattened along one direction, $\lambda_1 \approx \lambda_2 \gg \lambda_3$
- Spherical shapes, $\lambda_1 \approx \lambda_2 \approx \lambda_3$ which represent isotropic phenomena

Another type of tensor glyph, the **Reynolds glyph,** is computed in terms of the spherical coordinates (r, θ, ϕ) of each point, **p,** on a sphere. The glyph is created by setting the radial coordinate of each point to

$$r = \mathbf{p}^T \boldsymbol{D}\mathbf{p}, \tag{5}$$

where $\mathbf{p}^T$ is the transpose of **p**. The result is a peanut shaped glyph which is elongated in the direction of the major eigenvector. For positive-definite (PD) tensors (tensors with all eigenvalues being positive) all r values of the metric glyph will be positive. For tensors which are not PD the sign of r is usually mapped to color to give a visual indicator of the sign of r. In stress tensor visualization, this help differentiate states of tension and compression. Reynolds glyphs for the tensors in Eq. 4 are shown in Fig. 3.

The appearance of ellipsoid and Reynolds glyphs can be uninformative from some viewpoints. For example, it can be difficult to differentiate between a cigar-shaped ellipsoid and a pancake-shaped ellipsoid viewed edge-on. Superquadric glyphs (Kindlmann 2004) were proposed to overcome this visual ambiguity. Superquadric shapes can include ellipsoids and other shapes, such as cylinders and cuboids. Superquadric glyphs corresponding to the tensors in Eq. 4 are shown in Fig. 4.

Westin et al. (2002) developed a composite glyph to mitigate the problem of visual ambiguity. Their solution was a glyph which combined independent visualizations of linear, planar, and spherical shapes.

Cauchy stress glyphs, or quadric glyphs, are defined as the implicit surface

$$\boldsymbol{p}^T \boldsymbol{D}\boldsymbol{p} = \pm k^2. \tag{6}$$

These glyphs are useful for examining the case of pure shear in a solid.

Particle systems are a discrete approach to visually representing a tensor field using animation. Each particle is an icon or glyph representing a tensor which moves along the $\mathbf{v}_1$ field. The particle appearance changes as it moves to reflect the tensor at the current position. A GPU implementation was described by Kondratieva et al. (2005) to accelerate particle rendering and animation in the context of DT-MRI visualization.

Glyph based techniques are prone to some well-known problems. When applied to large datasets, the display can become too cluttered to be useful. In 3D datasets, the glyphs can occlude each other. The local structure that they convey can depend on viewpoint and at times become totally impossible to discern.

Glyph Placement

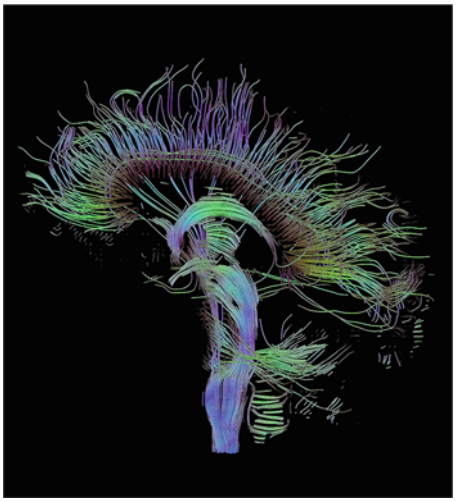
A naive approach to visualizing a tensor field is to simply place a glyph at each measured data location. However, whether the measured data are irregularly spaced or on a grid, this glyph

Tensor Field Visualization, Fig. 3 Reynolds glyphs

Tensor Field Visualization, Fig. 4 Superquadric glyphs

placement can give misleading results. Data points too far apart can make interpreting the field between points difficult. Dense data points can result in many glyphs which obscure each other. The pattern of datapoint locations, such as on a regular grid, can lead to visual artifacts which mask actual features in the dataset. It is difficult to elaborate an optimal strategy for glyph placement since it may be dependent on the specific dataset and the task at hand.

Kindlmann and Westin (2006) presented a strategy for placing tensor glyphs which emphasizes the coherent structures of DT-MRI that emerge along fiber tracts. They define attraction and repulsion forces between glyphs that move them into a packed arrangement such that overlaps are minimized and coherence along tracts is emphasized. However, placing tensor glyphs between datapoints raises the question of how to interpolate tensors.



Tensor Field Visualization, Fig. 5 Streamtubes representing white matter fiber tracts in the human brain. Sagittal view of DT-MRI (Figure 5 is reused under the creative commons license. The original version can be found at https://en.wikipedia.org/wiki/Diffusion_MRI#/media/File:DTI-sagittal-fibers.jpg)

Tensor Lines and Surfaces

Streamlines (or integral curves) are curves which are locally parallel to a vector field at every point along the curve. Streamtubes have a circular cross section and their axis is a streamline. Although streamlines and streamtubes are usually vector field visualization techniques, they can be adapted to reflect tensor field information by considering the vector field of v_1, the major eigenvector of each tensor in the field.

Soon after the development of DT-MRI, tractography (the process of tracing white matter pathways in the brain) was developed (Basser et al. 2000). Early approaches to tractography were inspired by streamline tracing techniques. By repeatedly stepping in the principal diffusion direction, white matter fiber tracts can be reconstructed. Tracts visualized as streamtubes are shown in Fig. 5. However, in DT-MRI tractography becomes unreliable in regions where anisotropy becomes low, so additional tensor information must be used to prevent meaningless streamlines from being created. With the second-order tensor model of diffusion, anisotropy may become low due to the absence of white matter or due to crossing or branching fibers.

"Hyperstreamlines" (Delmarcelle and Hesselink 1993) include additional information about the tensor field by generalizing the streamtube cross section from a circular shape to an ellipse. The geometry of that ellipse is defined by the other eigenvectors ($\mathbf{v}_2$ and $\mathbf{v}_3$) and eigenvalues (λ_2 and λ_3) of the tensor at each point.

Streamsurfaces forming continuous surfaces in regions where the diffusion ellipsoids have a flattened "pancake" shape have also been proposed to visualize tensor fields.

As with solving the problem of glyph placement, interpolation becomes a problem in streamline and streamsurface generation since we generally wish for the curves and surfaces to have a smooth high-resolution appearance with respect to the set of data points. Approaches to tensor field interpolation include linear interpolation of tensor components, log-Euclidean interpolation, and polynomial functions with physical constraints.

Tensor Invariants

Tensor invariants are scalar values computed from the tensor which are invariant under changes of

coordinate system. The eigenvalues of the tensor are invariants, and therefore many other invariants can be expressed in terms of the eigenvalues. A tensor field can be converted into multiple scalar fields of invariants which can then be visualized using scalar field visualization techniques, such as volume rendering, or the scalar invariants can be incorporated into other tensor field visualizations, such as determining the color of streamlines or glyphs.

Fractional anisotropy (FA) can be computed as the normalized variance of the eigenvalues,

$$FA = \sqrt{\frac{3}{2}} \times \frac{\sqrt{(\lambda_1 - \overline{\lambda})^2 + (\lambda_2 - \overline{\lambda})^2 + (\lambda_3 - \overline{\lambda})^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}, \tag{7}$$

where $\overline{\lambda}$ is the average of the three eigenvalues. FA has found much clinical success in assessing, for example, brain trauma, multiple sclerosis lesions, and stroke in DT-MRI. Geometrically, FA represents the elongation or eccentricity of the ellipsoidal glyph of a tensor. In diffusion tensor imaging, high FA values are associated with the presence of white matter fibers. Color FA images can be generated by combining intensity information from the FA image with color information computed from the PDD by $(r, g, b) = (|PDD_x|, |PDD_y|, |PDD_z|)$ as shown in Fig. 6.

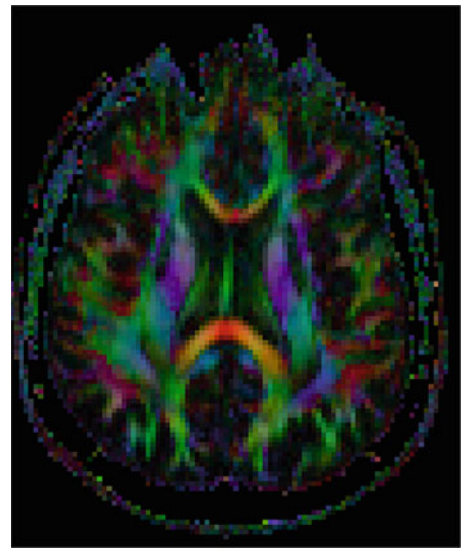
The shape of the ellipsoid glyph can be seen as a combination of linear, planar, and spherical elements, each of which can be quantified by the following measures: the linear shape index

$$CL = \frac{\lambda_1 - \lambda_2}{3\overline{\lambda}} \tag{8}$$

the planar shape index

$$CP = \frac{2(\lambda_2 - \lambda_3)}{3\overline{\lambda}}, \tag{9}$$

and the spherical shape index



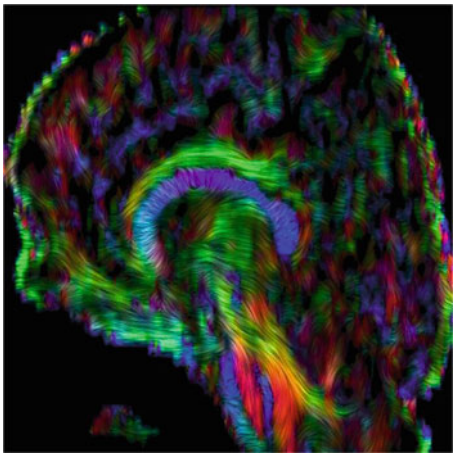
Tensor Field Visualization, Fig. 6 Color FA visualization of DT-MRI. Axial view of human brain

$$CS = \frac{\lambda_3}{\overline{\lambda}}. \tag{10}$$

These indices can be used to form composite glyphs, or to switch between visualization methods, such as using hyperstreamlines where *CL* is high, and glyphs elsewhere.

Texture-Based Approaches

Texture-based tensor field visualization methods create an image in which texture frequency and orientation represent the tensor field. Line integral convolution (LIC), introduced by Cabral and Leedom (1993), creates an image with slowly varying intensities along each streamline, and rapidly varying intensity perpendicular to streamlines. An LIC image is generated by blurring a noise image with a curvilinear kernel aligned with the streamline passing through each voxel. Hsu (2001) first explored the use of LIC on tensor fields to create DT-MRI images of cardiac muscle fibers in the human heart. McGraw et al. (2002) extended this technique by fusing the LIC texture and the color FA image to produce a visualization depicting diffusion direction and anisotropy, as shown in Fig. 7. Zheng and Pang developed "HyperLIC" (Zheng and Pang 2003), a technique which allows all three eigenvectors of the 3D



Tensor Field Visualization, Fig. 7 Line integral convolution visualization of DT-MRI. Sagittal view of human brain

tensor to contribute to the texture. Laidlaw et al. (1998) proposed a hybrid visualization approach using texture-mapped glyphs. The patterns on the resulting glyphs can portray all six unique symmetric diffusion tensor components (see Eq. 1). By overlaying the glyphs on a scalar image, such as FA, a layered image can be created.

Topological Approaches

Topological approaches to vector and tensor field visualization reduce the field to a sparse set of feature points and curves. Previous approaches to topological tensor field visualization defined degenerate points as locations where two or more eigenvalues are equal to each other. The topological skeleton of the tensor field can be defined as the set of degenerate points and the hyperstreamlines which connect them. The hyperstreamlines partition the tensor field into regions of homogeneous behavior.

Zheng et al. (Zheng and Pang 2004) described several categories of feature points and provided numerically stable methods for extracting them. The points were then connected to form feature lines. By using discriminant analysis, they were able to locate critical features with subvoxel accuracy. Several topological approaches specific to DT-MRI have been based on scalar field topology. Topological structures in scalar fields can be defined in terms of ridges, valleys, or crease lines. To apply these methods to DT-MRI, the scalar fields formed by tensor invariants are often considered. Tricoche et al. (2008) investigated tensor mode (eigenvalue skewness), and Kindlmann et al. (2007) considered fractional anisotropy (eigenvalue variance). Schultz et al. (2007) presented another approach using degenerate lines computed from probabilistic tractography. They also describe a robust method for computing crease surfaces from tensor fields.

Higher-Order Tensors

Visualizing fields of tensors of order greater than two has been a less active research area. Most of the proposed visualization approaches use glyphs. A limitation of the second-order tensor model of diffusion can be observed from the shape of its glyphs – multiple peaks cannot be represented. In terms of DT-MRI that means that when two fiber pathways intersect, the resulting ellipsoid looks like a "pancake," not a shape with two independent peaks. High-order tensors have been used to describe non-Gaussian diffusion by Ozarslan et al. (Özarslan and Mareci 2003). Diffusion within the brain can be non-Gaussian, for example, where white matter fibers bifurcate or intersect.

Due to the fact that diffusion is antipodally symmetric (equal in opposite directions), only even order tensors are valid diffusion representations. Fourth, sixth, and eighth order tensors have been proposed as models for diffusion.

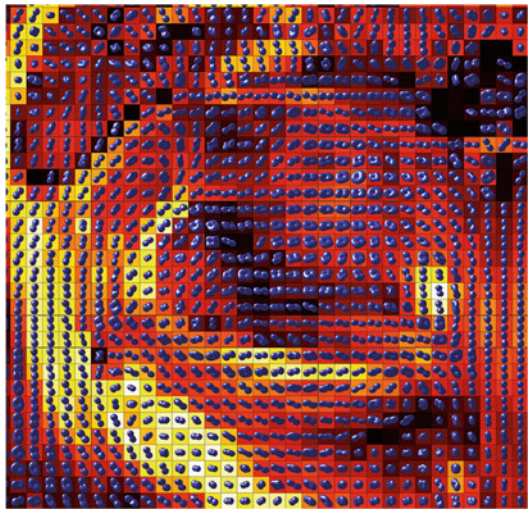
The second-order tensor Reynolds glyph described in Eq. 5 can be rewritten in tensor subscript notation as

$$r = \sum_i \sum_j \boldsymbol{p}_i \boldsymbol{p}_j \boldsymbol{D}_{ij}, \tag{11}$$

and this equation can be extended to fourth-order tensors as

$$r = \sum_i \sum_j \sum_k \sum_l \boldsymbol{p}_i \boldsymbol{p}_j \boldsymbol{p}_k \boldsymbol{p}_l \boldsymbol{D}_{ijkl}. \tag{12}$$

The resulting fourth-order tensor glyph will display peaks aligned with one or two fiber



Tensor Field Visualization, Fig. 8 Fourth order tensor Reynolds glyphs overlaid on a heat map of generalized anisotropy

directions. A higher-order tensor model is required in order to resolve more crossing fibers. An example of a 4th order tensor field visualized with Reynolds glyphs is shown in Fig. 8.

In solid mechanics, the fourth-order stiffness tensor, $\boldsymbol{C}_{ijkl}$, relates mechanical stress to strain by the generalized Hooke's Law,

$$\boldsymbol{\sigma}_{ij} = \sum_k \sum_l \boldsymbol{C}_{ijkl} \boldsymbol{\epsilon}_{kl}, \qquad (13)$$

where $\boldsymbol{\sigma}_{ij}$ is the second-order stress tensor and $\boldsymbol{\epsilon}_{kl}$ is the second-order strain tensor. Analysis and visualization of the stiffness tensor is important to understanding engineering failures due to fracture.

Tensorlines can be generated from higher-order tensors, but extracting the correct direction is confounded by several issues. First, we cannot simply compute eigenvalues and eigenvectors of a higher-order tensor – a more involved optimization scheme must be used to determine the directions of the peaks. Secondly, in high-order DT-MRI, the peaks in diffusivity no longer correspond to the underlying fiber directions. However, it is possible to efficiently compute a fiber orientation distribution (FOD) tensor (Weldeselassie et al. 2012) which represents the directions of the white matter fibers.

Scalar invariants computed from higher-order tensors, including a generalization of FA to high-order tensors (called "generalized anisotropy"), were presented by Ozarslan et al. (2005).

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Terrestrial Photogrammetry

► 3D Modelling Through Photogrammetry in Cultural Heritage

Texture Mapping

► Live Texture Mapping in Handheld Augmented Reality Coloring Book

The Art of Electroencephalography

► Movie-Making of Spatiotemporal Dynamics in Complex Systems

The Elder Scrolls V Skyrim

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Synonyms

Action Adventure Game; Role-Playing Game; Single-Player Game

Definitions

Single-Player Game	A game that is designed for single-player mode where only one player is expected throughout the entire gameplay.
Role-Playing Game	A game that each player assumes a particular role in the gameplay.
Action Adventure Game	A game that combines core elements from both action game and adventure game genres

Introduction

The Elder Scrolls V Skyrim is a single-player role-playing RPG game. Bethesda game studios developed Skyrim and published it through Bethesda Softworks. Released in 2011 for PlayStation 3 and Xbox 360, this game has gone on to win numerous awards and more than 200 Game of the Year awards. Skyrim is an open-world game that allows the player to explore the world of Tamriel. Players can explore dungeons, complete quests, and craft new weapons and equipment (Hodgson et al. 2012; Elder Scrolls 2022).

Gameplay

The Elder Scrolls V Skyrim is primarily a first-person RPG game (with an optional third-person

view) that utilizes diverse fighting styles. Players can use one-handed weapons such as swords and maces or two-handed weapons such as war hammers and axes. Players can also use magic spells such as fire and ice to combat enemies. Other aspects of gameplay include archery, which allows the players to fight enemies with bows and other ranged weapons such as a crossbow.

DLC

Skyrim includes three DLCs. These DLCs contain new areas and side quests for the character to complete. The expansions include Dragonborn, Dawnguard, and Hearthfire. The Dragonborn DLC introduces new areas to the player, such as the island of Solstheim. On this island, the players venture on a quest to stop the false Dragonborn Miraak. The island offers new areas to explore, weapons and armor, and creatures and plants. Dawnguard introduces Vampires into the world of Skyrim. This DLC allows players to befriend and join the vampires or join the Dawnguard and fight the vampires. The vampires will take you on a variety of quests with the end goal of helping the vampires block out the sun. While the other two expansions offer plenty of updated content, Hearthfire is a much smaller DLC. Hearthfire allows the player to construct their own home within Skyrim. Players can customize their homes to their liking and decorate them any way they choose.

Plotline

The main story focuses on the player's character, the Dragonborn, which can talk and communicate with dragons via dragon shouts. The main quest line of Skyrim presents the player with the task of stopping the evil dragon Aulduwin who threatens to consume all of the mortal world. It is up to the Dragonborn to save the continent of Tamriel from certain doom. The main quest line is a wonderful place to start within the massive world of Skyrim to gain levels quicker and unlock more skills.

Character Creation

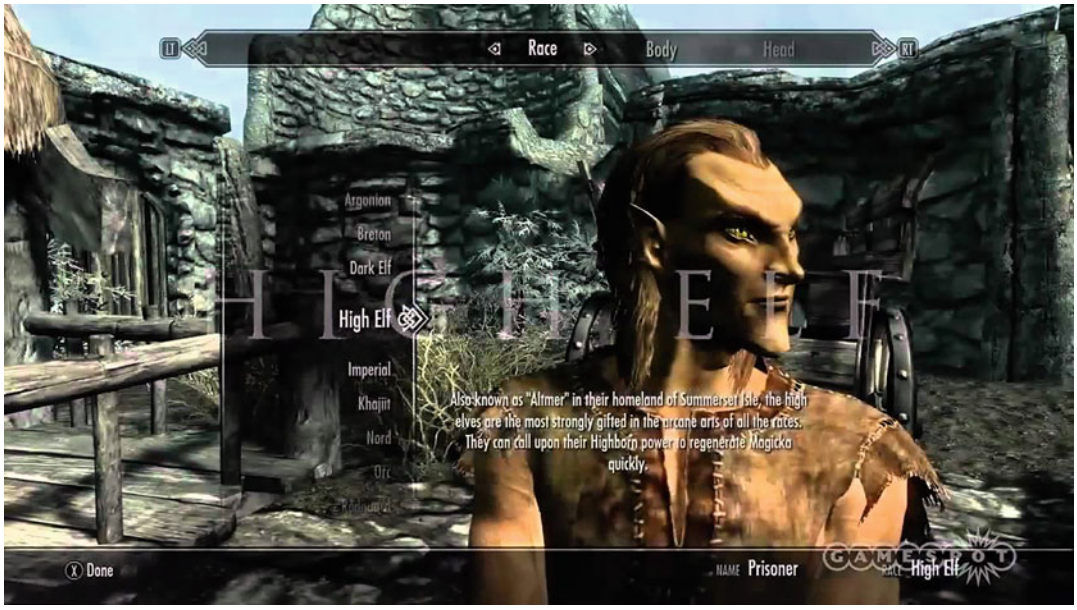
Skyrim allows the player to customize their character by choosing a variety of races in the world. Each race has a unique race ability that other races in Skyrim do not have (see Fig. 1). For example, some of the races in Skyrim include Argonians. These lizard-type creatures have a unique ability to hold their breath underwater for extended periods. Other races include the Nords, High Elves, Khajiit, and Wood Elves. The High Elves have bonuses to magical spells, and the Khajiit have increased thief skills such as improved stealth and pickpocketing. Nords are the humans in Skyrim, and they have increased resistance to the cold and are naturally better with swords and hammers. Wood Elves have increased benefits from archery. Several other Skyrim races are worth checking out, such as the Redguard and the Orcs.

Skill Trees

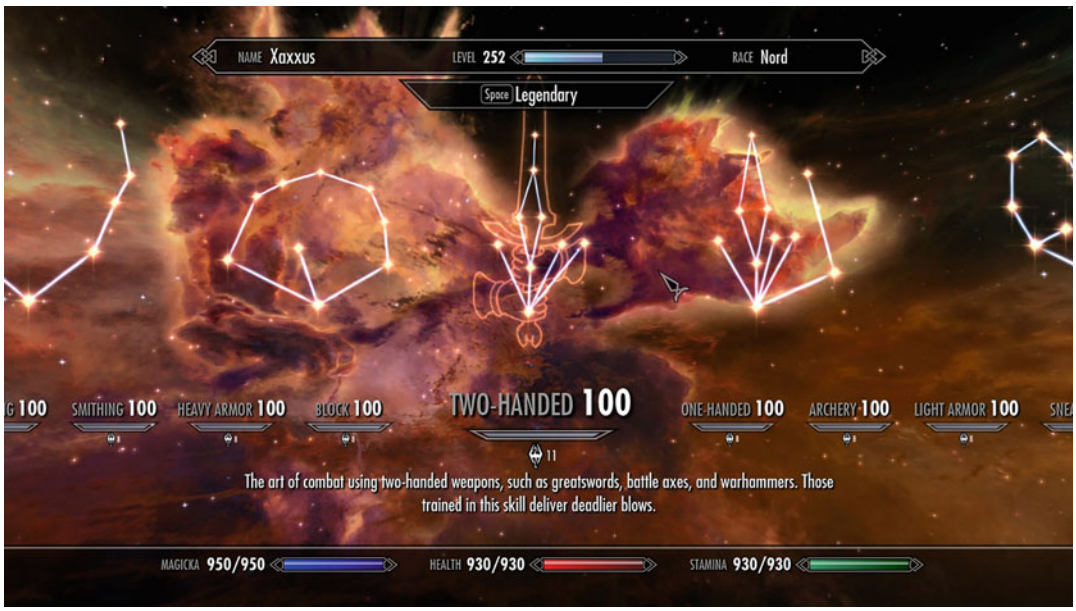
Skyrim provides players with a unique leveling system that is primarily skill-based. Each time you level up, the player gains skill points. The character can use these skill points to level the various skill trees in the game. The skill trees consist of three main sections. These include the mage, warrior, and thief trees (see Fig. 2). The mage class tree contains improvements to various spell classes, such as destruction and alteration. The warrior section focuses on improving one-handed or two-handed skills with weapons. Finally, the thief tree includes enhancing the ability of stealth, lock picking, and pickpocketing.

Dragon Shouts

As a Dragonborn, the player can cast what is known as dragon shouts (Maher 2022). These are magical abilities that are cast from the character's mouth. These shouts range from summoning dragons to throwing enemies backward. Characters can learn a dragon shout by learning the



The Elder Scrolls V Skyrim, Fig. 1 Skyrim Character creation screen: High Elf



The Elder Scrolls V Skyrim, Fig. 2 Skyrim Warrior Perk Tree

words of the shout. Shout words unlock by finding word walls. Word walls contain the words of ancient shouts. The player discovers word walls by exploring the Skyrim terrain. Once the player discovers a shout, the player can unlock more ancient dragon words to harness the full potential of a shout. Harvesting dragon souls of slayed dragons unlock these ancient words.

Holds

The world of Skyrim splits into various regions. Each of these regions has a significant hold or city. Holds are considered the major administrative sections of Skyrim. There are nine essential holds scattered across the landscape of Skyrim. Some of the major cities in Skyrim are Whiterun, Riften, Markarth, and Solitude (the capital city). These cities offer the player various shops to buy weapons and armor. Other shops also allow the player to purchase potions and enchantments with in-game gold that can improve the player's weapons and armor. The cities of Skyrim are also an excellent place for players to find side quests or jobs to complete.

Mods

One of the unique things about Skyrim is its large community of modders and creators. Modding a game allows the player to add new things to the game. For example, there is a mod to spawn chickens that would explode when shot with a bow and arrow. The Skyrim modding community has helped keep Skyrim thriving by adding mods that completely overhaul the game experience. There are over 70,000 available mods for Skyrim that players on the PC platform can experience completely free of charge. In addition, the newer generations of consoles have also opened support for mods. As a result, mod support has allowed console players to experience a wide range of mods and community-made content.

Reception

Since the release of Elder Scrolls V Skyrim in 2011, the game has sold over 30,000,000 copies worldwide. Skyrim has been Bethesda game studios' most successful game ever. Even their other popular titles, such as Fallout, have not surpassed this number in sales. In addition, Skyrim has survived three generations of consoles, releasing on the Xbox 360 and PlayStation 3, Xbox One and PlayStation 4, and more recently the PlayStation 5 and Xbox's Series X console.

Conclusion

There are many ways that players can approach the world of Skyrim. It offers players a variety of classes and characters, allowing them to explore the world with their preferred playstyle. The ability for the player to adapt various playstyles keeps Skyrim fresh and engaging for years. As a result, Skyrim has become one of the best-selling games of all time, having sold over 30,000,000 copies within a decade (Edwards 2021).

Cross-References

▶ Narrative in Video Games

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The New Age of Procedural Texturing

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Synonyms

CG, computer graphics; HD, high definition; UI, user interface; UX, user experience; VFX, visual effects

Definition

In the computer graphics and game development worlds, a *texture* is the digital representation of the appearance of a surface; *procedural texturing* is the process of using an algorithm in order to generate a texture.

Introduction

We believe we have entered a new age for procedural texturing, an age where these techniques are not only interesting to the theoretically concerned, the technically minded 3D artists who put them into practical use, but to a wider audience. Procedural techniques have indeed now extended past the most high-end of game development studios and the VFX and animation houses that gave them their first homes. As this new age progresses, the presence and use of procedural techniques for creating textures are only going to grow more entrenched in the years to come.

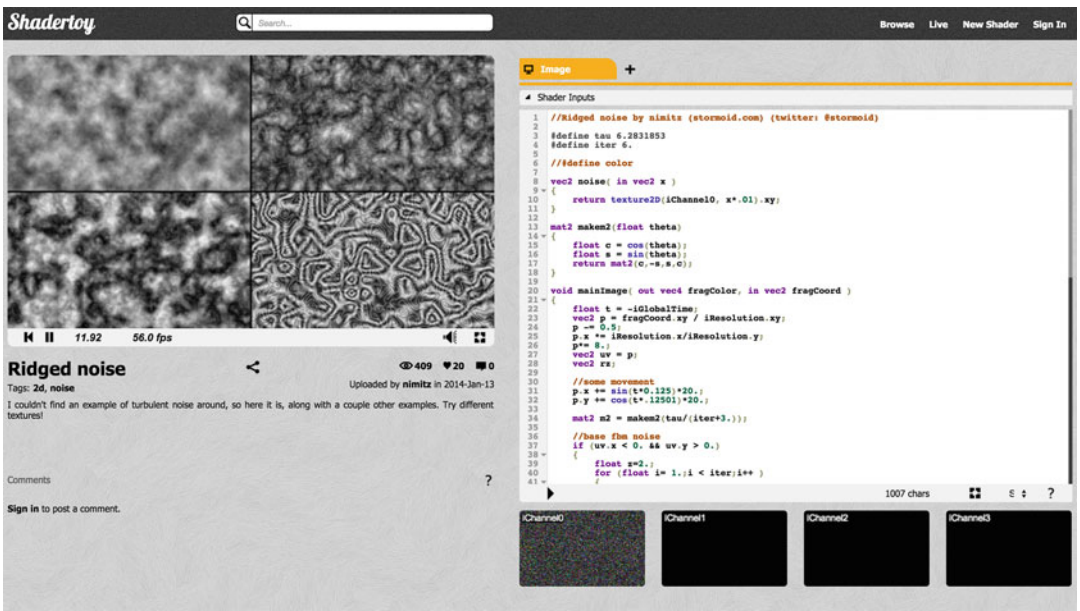
In this entry, we will focus mainly on the reasons why this new age is upon us and on some of the new techniques and approaches that have emerged in the past few years. The subject of procedural texturing, in itself, is already very known and covered (see in particular Ebert et al. 1998 for more on this topic), so we will not go into much detail about the science behind procedural texturing; rather, we'll focus on the exploration of new trends emerging from the visual effect and gaming industries.

What Is a Procedural Texture?

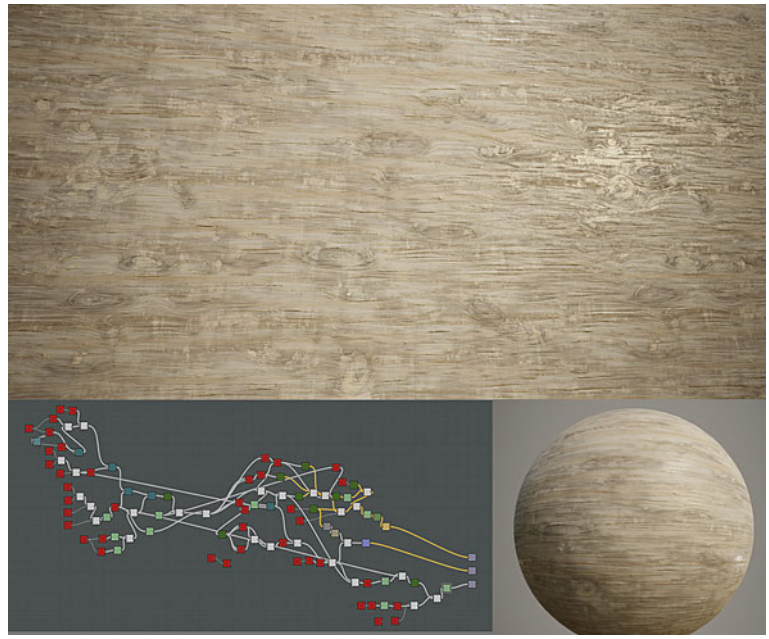
A procedural texture is a computer-generated image created using an algorithm (this is where the term *procedural* is derived from: a *procedure* is driving the process), instead of a digital painting or image processing application such as Adobe™ Photoshop™ (see Figs. 1 and 2).

Procedural texturing involves a two-step process:

- **The "authoring" phase**: During this first phase, procedural texture authors pick and combine the techniques they want to use, set the parameter values that drive these techniques, and expose the meaningful parameters



The New Age of Procedural Texturing, Fig. 1 The four textures on the *left* have been procedurally generated using four different parameter values from the procedure code on the right (Extract from Inigo Quilez's online tool Shadertoy Beta; see Quilez n.d.)



The New Age of Procedural Texturing, Fig. 2 This plywood procedural material is derived from the procedure visually represented as a graph at the *bottom left*. Tool used, Substance Designer™ by Allegorithmic™ (Extract from Hugo Beyer's online portfolio; see Beyer n.d.)

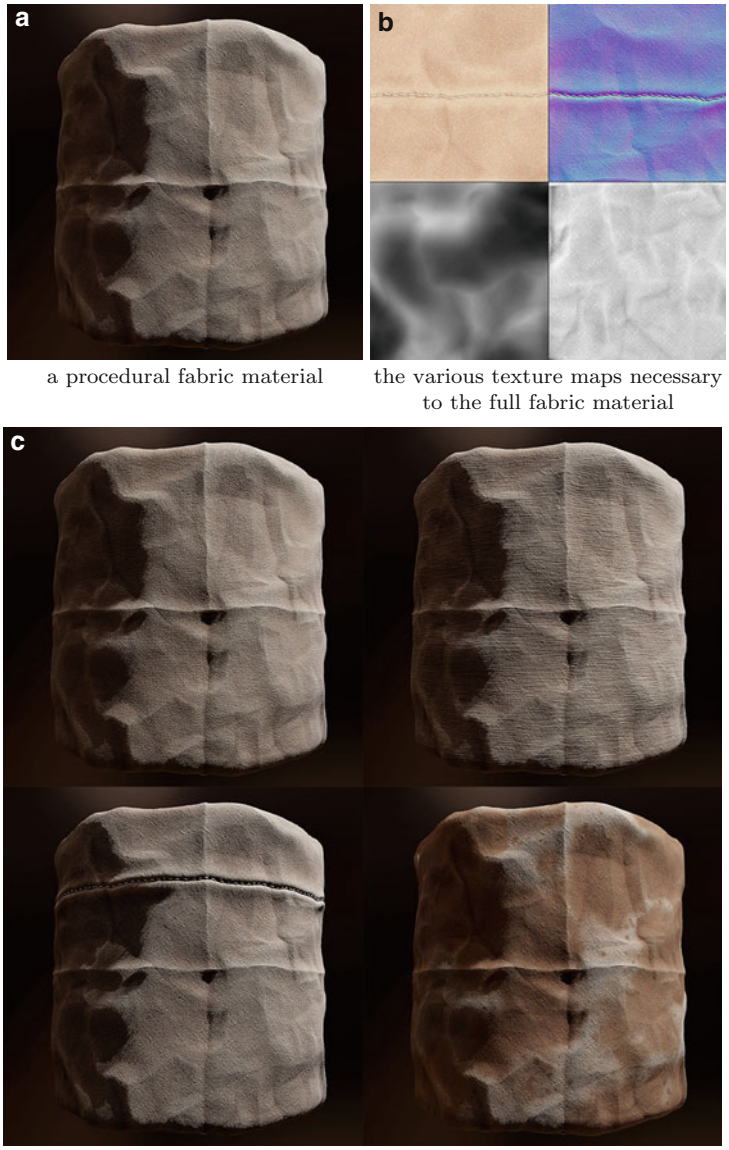
allowing to change the resulting textures' look and feel (see Fig. 3). These parameters can be of any type, from numerical values (the fractal dimension of a fractional Brownian motion generation algorithm, for instance; see Sébastien et al. 2000) to complex multi-array data (an image, i.e., an array of RGB numerical values, can in that respect be treated as a parameter to procedural texturing algorithms; see Fig. 4). At this authoring stage, the result of the procedural texturing process is not visible yet: The generation phase needs to be activated.

- **The "generation" phase**: During this phase, the program and parameter values defined in the previous phase are interpreted and executed, in order to produce the final output(s) (in the particular case of procedural texturing: textures). The process is *realized*. Two main methods can be witnessed (see Ebert et al. 1998 for more details):
  - **Implicit generation**: In this case, the generation algorithms are analytically defined, allowing to be easily called in a random fashion. Usually, rendering engines will ask for a certain (u,v) value to be generated in the parameterization space for the given geometry upon which the procedural textures are applied. With this approach, no bitmap texture is stored in memory, usually at the cost of "expression power."
  - **Explicit generation**: Here a resolution for the final output textures is set, and the whole texture is rasterized, in one and only one step, and "baked out" as a bitmap texture, stored in central or video memory to be accessed by the rendering engine. These explicit techniques allow for a very wide range of output, referred to as "high power of expression."

In both cases, the generation phase is done by a *generation engine*.

Why Use Procedural Texturing?

The motivation for using procedural texturing can be very varied, going from speed of authoring to fast delivery of content. Here are some of the most important reasons why creators should use procedural texturing:



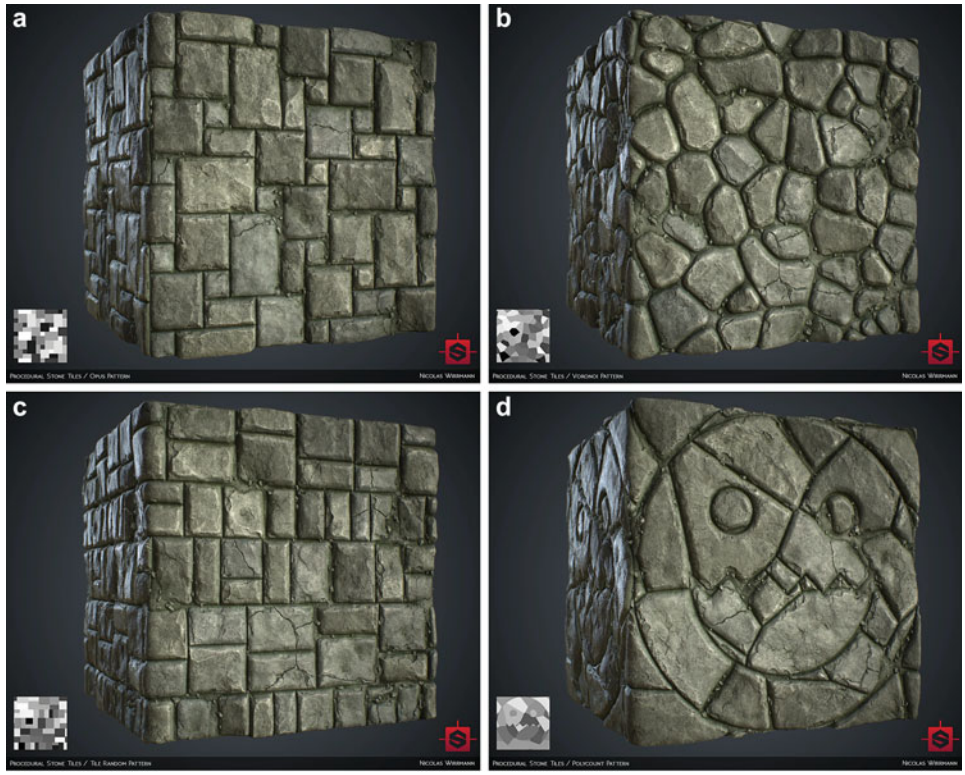
a procedural fabric material

the various texture maps necessary to the full fabric material

variations of the same fabric procedural material

The New Age of Procedural Texturing, Fig. 3 By playing on some parameter values of the procedural texturing algorithm created to generate this fabric texture, one can obtain variations in the look and feel: fabric type, level of dirt, the presence or absence of stitches, etc. (Extract from the work of Bradford Smith; see Smith n.d.)

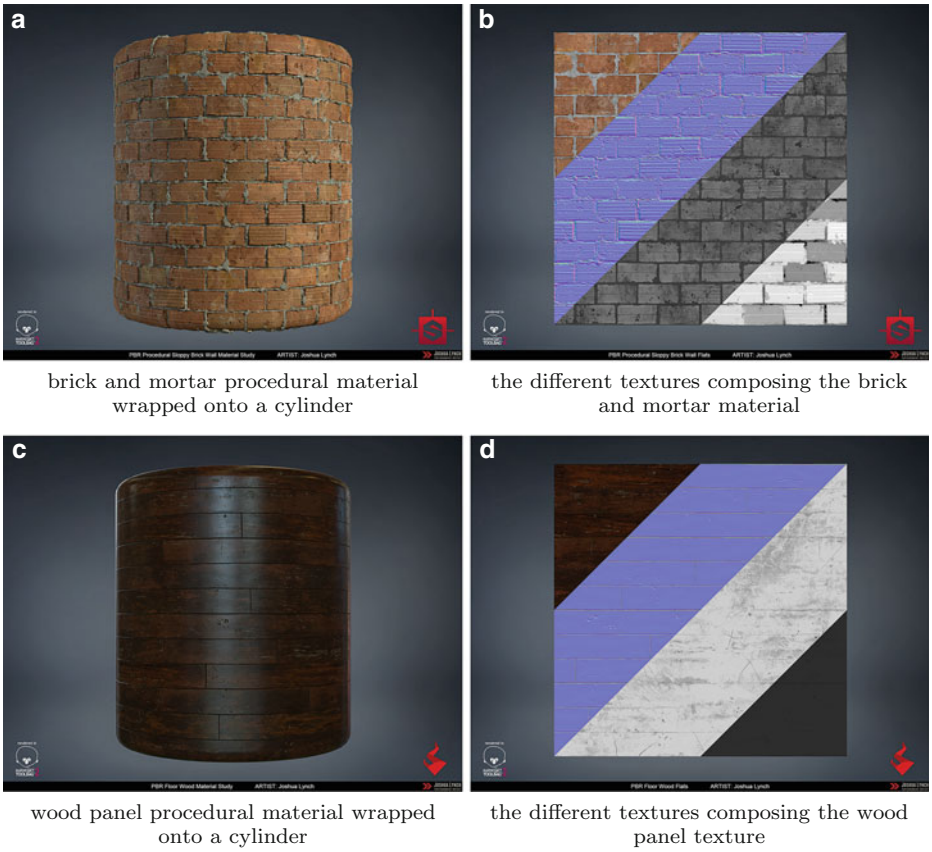
- **Productivity**: The rise of Ultra HD and even higher resolution displays, combined with the increase in project sizes (see games such as Rockstar™'s Grand Theft Auto™ where the player can freely explore gigantic areas), again combined with the always decreasing (relative to the amount of content produced) production budgets (and margins to creators) of computer graphics and digital assets represents a significant challenge to creative teams. A large volume of assets needs to be created as quickly and cheap as possible, at the utmost levels of quality. Here procedural texturing, with its "data amplification" nature (see Ebert et al. 1998), can definitely help, as once a procedural texture definition is set and approved for one realization of the process, one can change parameters, and in particular the random seed used when generating the textures (see Ebert et al. 1998), to automatically create a theoretically infinite number of other textures. These will look like they are



The New Age of Procedural Texturing, Fig. 4 Images can be treated as input parameters of procedural texturing techniques. In these procedural materials, images at the *bottom left* are used to drive the positioning and shape of the stones in the final material (Extract from the work of Nicolas Wirrmann from Allegorithmic; see Allegorithmic et al. (2003). Logo at the *bottom left* of image **d** is the Polycount logo ("Greentooth"), the reference discussion forum when it comes to technical 3D art; see Polycount n.d.)

part of the same "family" but will be different when compared pixel by pixel (see Ebert et al. 1998). A lot of creative studios now use procedural techniques to produce very large amounts of textures, used either as is or as a building block to other more complex textures, using a combination of various creation techniques. The gains are nonlinear and higher as time passes as creators can hoard techniques and texture definitions in a library of generative, versatile content. Finally, if the art direction for the content changes at some point in the process, it is easier than ever to change one input value to all the procedural textures and then regenerate all your batch via a single command. Here again, the gains in productivity are immense.

- **Complex texture production**: Sometimes replicating an effect witnessed in nature or fantasized by an artist is not an easy task. References can be lacking, and in that case, iterations are the key to success in a trial and error process. Not having to paint a new texture for every iteration, or take a picture of an effect so it can be processed and used as a proper texture, can lead to huge time savings. Playing with parameters and simply calling again against the generation engine is a very important time saver (going back to the previous, productivity-centric point), making it a good step toward the production of the desired look. It is also worth noting that the level of complexity that noise generators especially can produce is something that is very hard to replicate by hand. Here again, procedural noise



brick and mortar procedural material wrapped onto a cylinder

the different textures composing the brick and mortar material

wood panel procedural material wrapped onto a cylinder

the different textures composing the wood panel texture

The New Age of Procedural Texturing, Fig. 5 These textures (all the components of the digital materials presented here, like "albedo," "normal," "roughness," and "metallic" maps) would have been extremely complex and time-consuming to produce by hand. Procedural techniques, on the other hand, produce these textures quite easily (Extract from Joshua Lynch's online portfolio; see Lynch 2015)

generation and overall texturing techniques can prove very helpful (see, for instance, Fig. 5).

- **Look consistency**: Applying procedural generation techniques in the production of a large amount of textures can also prove very important to ensure the look consistency of the assets. Most of the time, even if not guaranteed, changing parameter values will lead to textures sharing the same visual properties. Also, by controlling the procedural techniques used by creators, one can make sure the outputs of these processes and the processes themselves respect specific properties and constraints, respectively, such as "the roughness map only contains values within a certain range," or that "the normal map is only computed after all the computation on the height maps have been done, this latter map being in grayscale 32f format instead of 24b colour for the albedo map." An automated process can definitely help ensure rules are respected and that the assets maintain a consistent look once imported in the game engine.
- **Data size optimization**: Procedural textures description files, especially when they are of the "purest" form (see "Definition" section), can be very compact. Due to the descriptive nature of procedural techniques, and the two-step process (authoring, then generation; see section "What Is a Procedural Texture?") of procedural texturing, a procedural texture description file will typically weigh a few kilobytes instead of several megabytes or

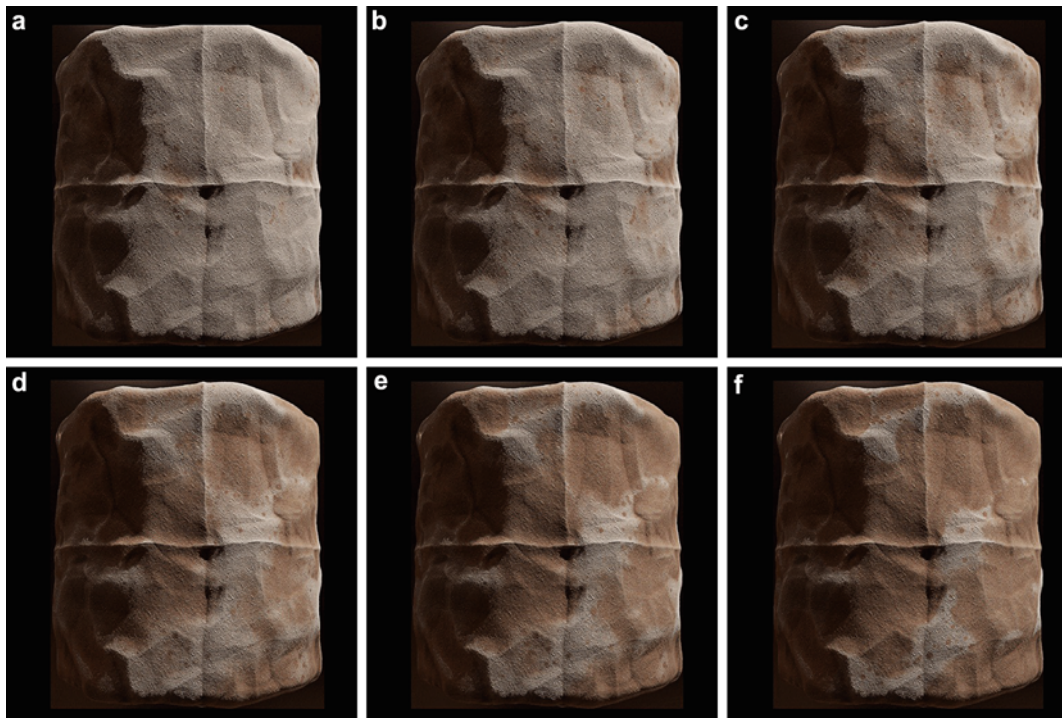
gigabytes in relation to their bitmap equivalent. This is often referred to as "data amplification" and can prove useful when the generation process can be done on the "client side": In the case of a mobile or online game, for instance, the players will only download a set of very light description files on their local device (the "client"). These files are then generated locally by the generation engine whenever they are required to display (install-, load-, or runtime). This generation process is often faster than the download time, making the benefits twofold: faster download times and lighter network consumption.

- **Animated and customized textures**: Because procedural textures are defined by parameters and generated in a two-step process through a generation engine, and in the case that generation engine is embedded in the playing application (i.e., game or virtual experience, for instance), one can modify these parameters' values at runtime and call against the engine to regenerate the output textures with a new look and feel to them. This leads to very interesting effects such as animated textures (see Fig. 6), adaptive textures (more or less dirt after an explosion occurred in the area where they are set, for instance), or simply user customization (the idea of letting the player of a game choose parameter values herself to "tweak" the look of the assets to their desire: see Fig. 7).

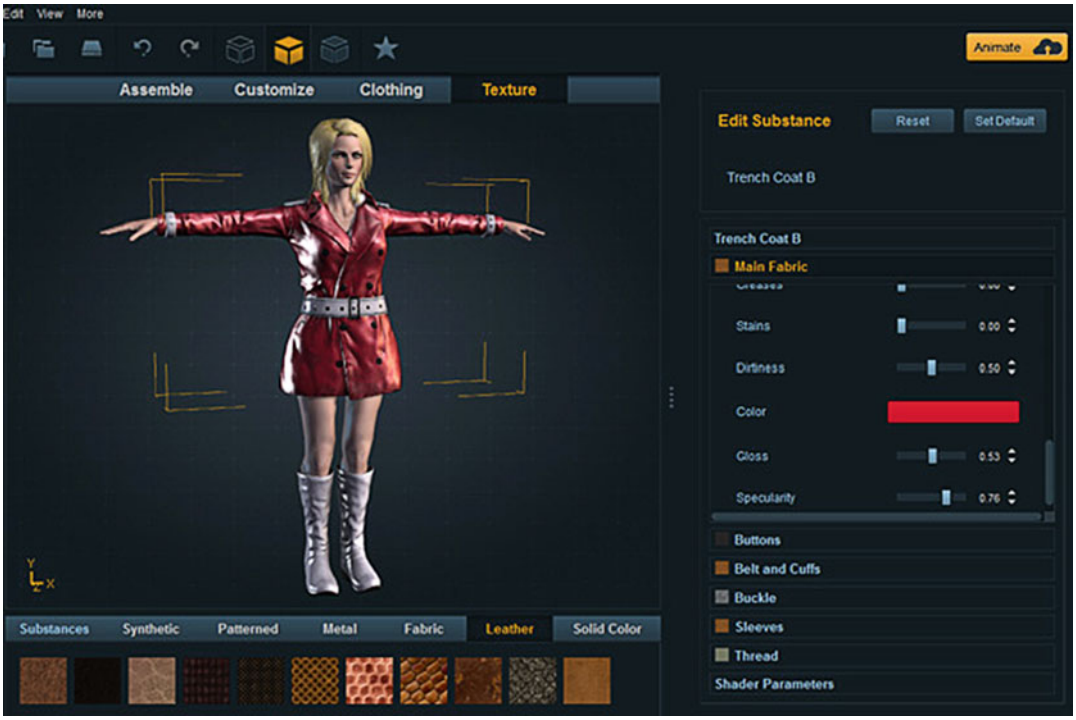
Misconceptions About Procedural Texturing

Procedural texturing has suffered in some circles from a bad reputation. Among the main misconceptions, we can cite:

- **Procedural textures look too "mathematical"**: It is true that when confined to 30+-year-old techniques, the outputs one can obtain by using "colorized" noise functions can look



The New Age of Procedural Texturing, Fig. 6 In these realizations of the same procedural texturing algorithm, defining parameters can make the fabric more wet and dirty (Extract from the work of Bradford Smith; see Smith n.d.)

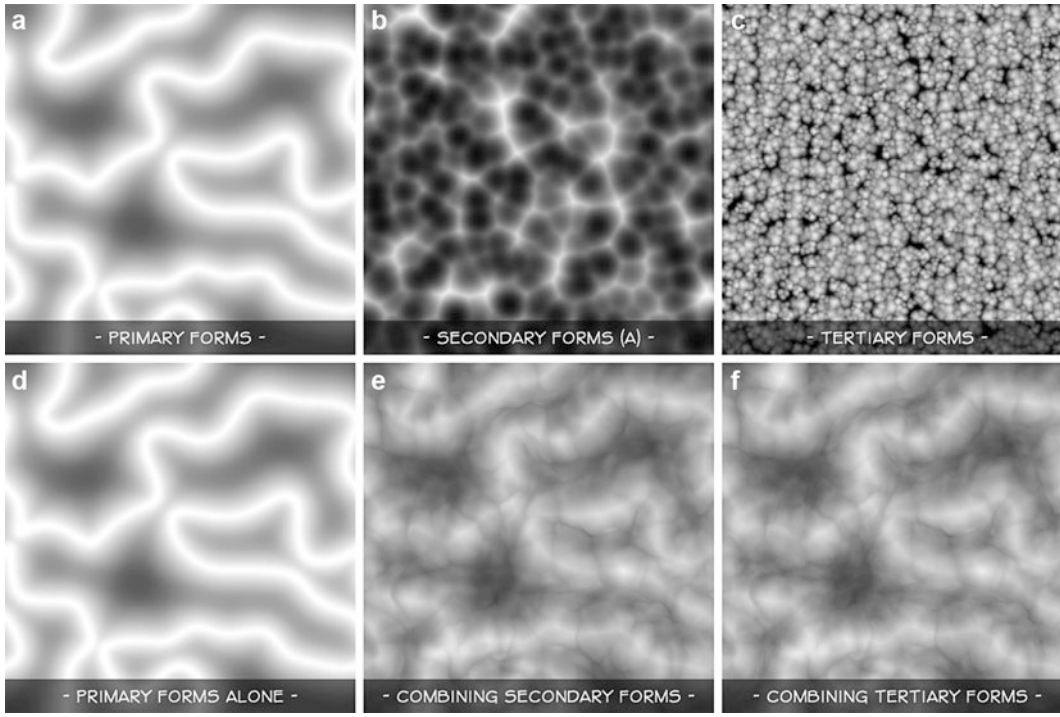


The New Age of Procedural Texturing, Fig. 7 The textures on this virtual character are fully procedural and can be controlled by the operator via the parameters on the right side of the interface (Extract from Adobe™ Fuse™; see /https://community.mixamo.com/hc/en-us/articles/203533673-Tutorial-Create-a-Character-with-Fuse)

fake or the result of a very mathematical process. Just like any other tool, procedural texturing techniques can bias outputs, so it is up to the artist to remove this by enhancing the techniques and/or use of these techniques. Combining various outputs often breaks this "mathematical look" (see Figs. 8 and 9), and today's production of procedural textures is now operating at the highest quality levels.

- **Procedural textures are only for tileable textures**: This point also inherits from 30+ years of procedural texturing techniques, the early stage of which found most techniques being used to produce square, tiling textures that would be repeated over surfaces in a way that optimized video memory usage and accesses. But there is no limitation for procedural textures to be evaluated directly onto a 3D surface and/or to take into account the geometry onto which the textures are then wrapped (see Figs. 10, 11, and 12 and tools like Substance (Allegorithmic et al. 2003)).
- **Procedural texture limits artist's creativity**: Up to now, the availability of tools and knowledge needed to advance procedural techniques were limited. This converges with an outdated view that believes procedural textures should be only evaluated at runtime, leading to techniques that produce undesired outputs, especially with regard to their artistic value. A lack of user input is indeed frustrating to artists. This aspect is now mostly outdated: See section "The New Age of Procedural Texturing" and the numerous counterexamples displayed in this article.
- **Procedural textures are "replacing" artists**: Productivity is one of the main advantages of using procedural texturing. In my observations, most studios that implement procedural texturing techniques enjoy more creation time, thanks to the practical use of these techniques. This time is then used to increase the quality of their final textures. Procedural textures are also used as a way to quickly

The New Age of Procedural Texturing, Fig. 8 This photo-realistic "Sandy Ground" procedural material is the result of the combination of several noises; see Fig. 9 (Extract from the work of Bradford Smith Adobe™ Fuse™; see Smith n.d.)



The New Age of Procedural Texturing, Fig. 9 In order to produce the procedural "Sandy Ground" material presented in Fig. 8, author Bradford Smith combined three different, procedural noise functions: (d) = (a). (e) = (a) + (b), and (f) = (a) + (b) + (c). (f) is the final result, utilized as a height (or displacement) map in Fig. 8. Although each "form" or noise function is the result of a pure mathematical process, the end result is photo-realistic (Extract from the work of Bradford Smith; see Smith n.d.)

generate a texture draft that can then be reprocessed, or sometimes completely redone, by hand. My view is that procedural texturing will only replace the mere, repetitive texturing tasks with no added value, rather than completely "replace artists": Artistic vision is still key in the texture creation process.

The New Age of Procedural Texturing, Fig. 10 This character has been textured using a procedural, nondestructive methodology offered in Allegorithmic™ Substance™ Designer™ (Extract from the work of Samuel Compain; see Compain n.d.)

- **Procedural textures are slow to compute and should only be implicitly evaluated**: A higher complexity in the procedure necessary to generate textures at the desired graphical level implies longer computation times. Combined with limited, available resources on devices, this factor can limit the spread of the techniques. Also an inherited thinking is that procedural textures are necessarily implicitly evaluated, which dramatically limits the power of expression of the techniques at hand. This point is addressed at length in section "The New Age of Procedural Texturing."
- **Procedural textures are barely used in real production**: All the limitations and misconceptions above have hindered the spread of procedural techniques in the past. That being said, and this is one of the main inspiration points behind this article, their now pragmatic use (see section "The New Age of Procedural Texturing") has helped spread usage in production. At the time this article was published, a very significant percentage (25 %+) of AAA games currently being produced make a large use of procedural techniques.

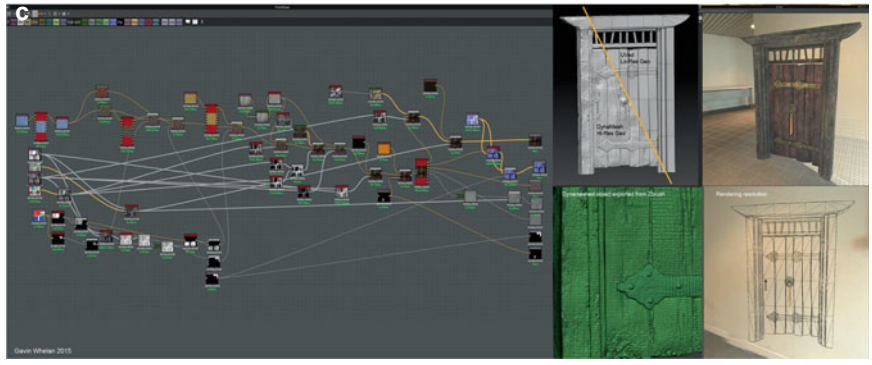
The New Age of Procedural Texturing

This new age is made possible in large part by a combination of two categories of factors: human and technical.

- **Procedural techniques at authoring time**: First, artists have realized that *procedural texturing finds maybe its best application case during the authoring phase of the content*, instead of the runtime phase. In fact,

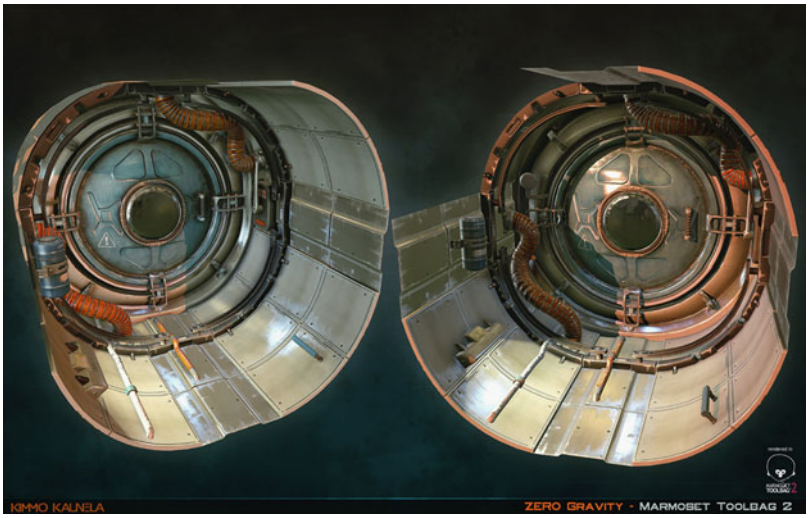
this scene has been entirely textured using a procedural approach

most of the procedural textures in this scene are not mere tiling textures, but adapted to every, specific asset



the procedural texturing process described in the graph on the left is dedicated to the door mesh on the right

The New Age of Procedural Texturing, Fig. 11 All elements composing this scene have been produced using a procedural, nondestructive methodology offered in Allegorithmic™ Substance™ Designer™ (Extract from the work of Gavin Whelan; see Whelan n.d.)



The New Age of Procedural Texturing, Fig. 12 This scene has been entirely textured using Allegorithmic™ Substance™ Designer™, a procedural texturing tool of the latest generation. Note how the mesh properties are taken into account in the process, such as on the edges of metallic parts – material is more aged in these areas (Extract from the work of Kimmo Kaunela; see Kimmo n.d.)

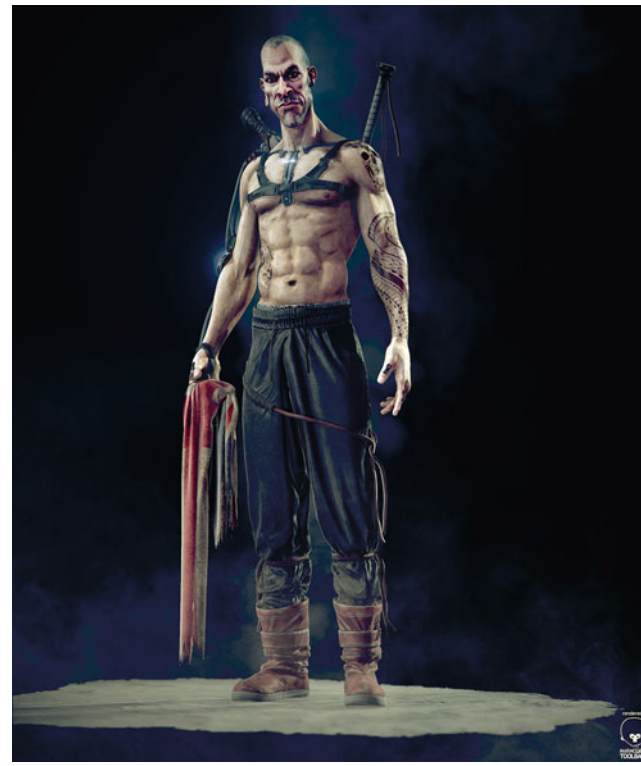
The New Age of Procedural Texturing, Fig. 13 This scene has been textured using a pragmatic approach in Allegorithmic™ Substance™ Designer™: a mix of procedural and bitmap elements (Extract from the work of Koola; see Koola n.d.)

procedural texturing in most studios today is used as a tool more than a means, and the output of this procedural texturing process is simply "baked" out as a set of bitmaps. These bitmaps can then be modified using traditional tools and techniques and consumed using traditional techniques by game and rendering engines alike. This way of using procedural techniques and tools eradicates most of the drawbacks that artists and engineers might have experienced by using procedural textures at runtime (see section "Misconceptions About Procedural Texturing").

- **A pragmatic use**: The large trend one can observe now is the *mix of techniques* used by the most advanced texture artists in the industry; using whatever tool is available and best suited for the task will be the choice of reason, and these tools and processes will be integrated in a holistic process made possible in particular by the "authoring-time" centric creation process described earlier (see, for instance, Figs. 13 and 14). This is a trend we will see getting stronger in the years to come as new artists begin to be freed from the misconceptions described in section "Misconceptions About Procedural Texturing."

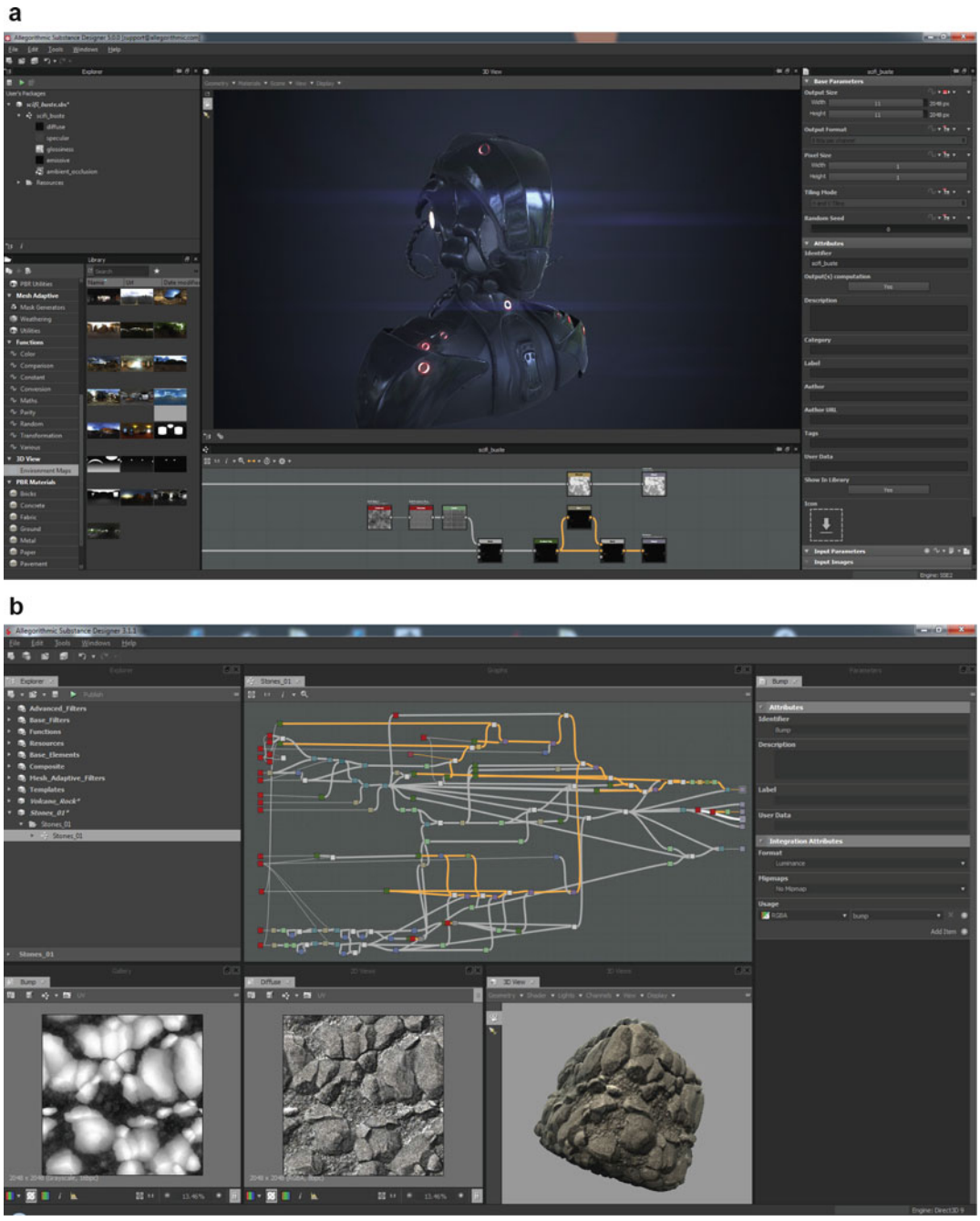
The second category of factors is technical:

- **Available computational power**: The amount of computational power available to creators, whether on desktop computers, mobile devices, or via cloud-based servers, is now higher than ever and has reached a point where generating content using procedural techniques is a viable option. Computationally expansive techniques, such as iteration-based algorithms, can now be put in practice.
- **Advances in computer science**: Techniques such as machine learning have made very important leaps in the past years, and it is to be expected that these approaches, which are based on training a set of algorithms to produce textures according to an inputted set of examples, will lead to new advances in the field.

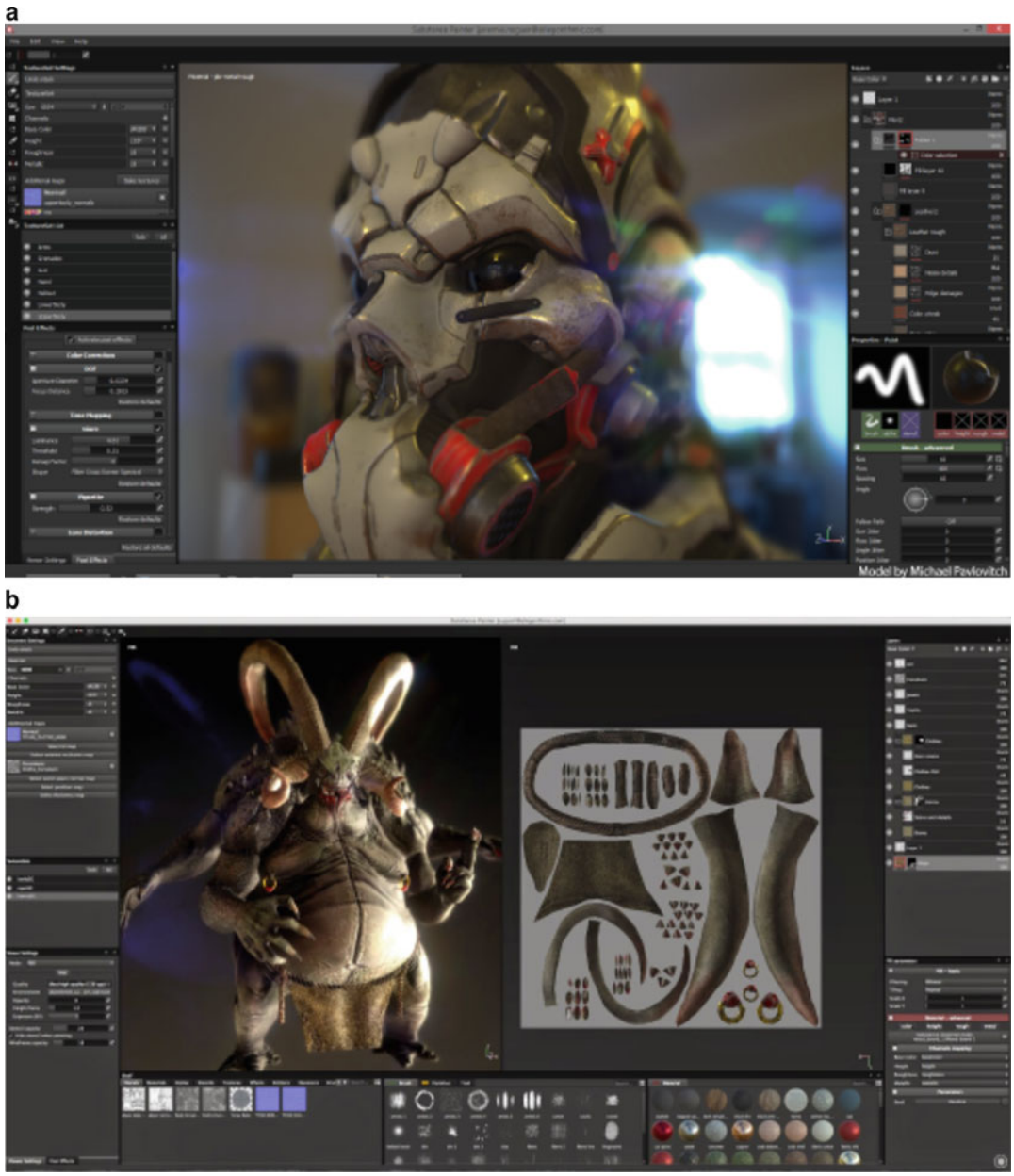


The New Age of Procedural Texturing, Fig. 14 This character has been textured using a mix of procedural techniques and handcraft. It is representative of the latest advances in texturing: a pragmatic use of all available techniques at hand, including procedural texturing (Extract from the work of Juan Puerta; see Puerta n.d.)

- **Available, more accessible tools**: Advances in UI and UX practices, combined with the rise of new tools dedicated to procedural texturing, such as the Substance™ tool suite that my company Allegorithmic™ develops of course (see Allegorithmic et al. 2003 and Figs. 15 and 16),

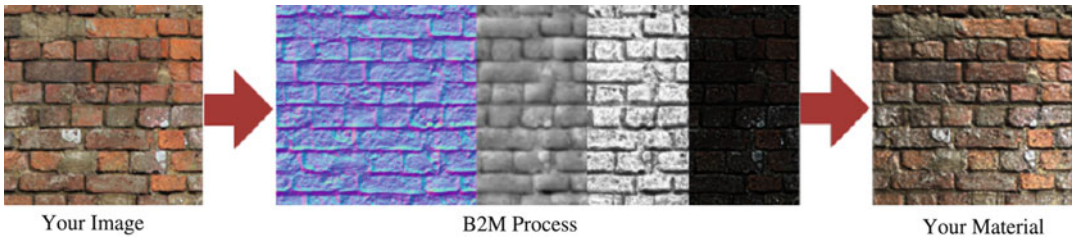


The New Age of Procedural Texturing, Fig. 15 Substance Designer™ by Allegorithmic™ is a tool largely (but not exclusively) dedicated to the creation of procedural textures while still being accessible to every artist, thanks to its advances in UI and UX (See Allegorithmic et al. 2003)



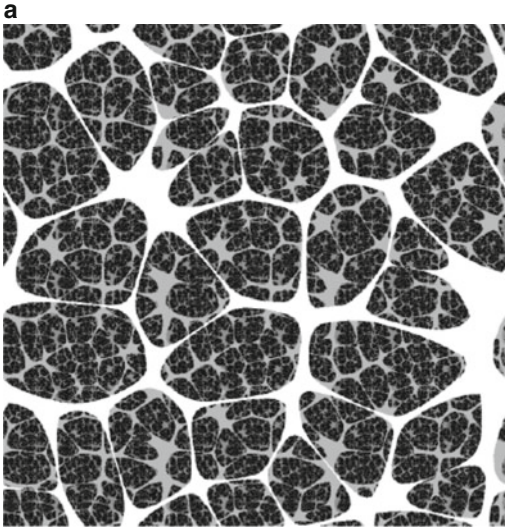
The New Age of Procedural Texturing, Fig. 16 Substance Painter™ by Allegorithmic™ makes a large use of procedural texturing techniques on top of more traditional hand-painting features (See Allegorithmic et al. 2003)

and others like Quixel Suite™ (see Quixel n.d.), 3DCoat™ (see 3D Coat n.d.), and the always relevant Side Effects Software™ Houdini™ (see Side Effects Software n.d.), have definitely supplanted the older generation of tools. More importantly, these tools are easy to use and do not require advanced mathematical or computer science and programming knowledge to be able to produce efficiently and professionally procedural textures. Their price points and dedicated business models make them accessible to smaller studios as well as enthusiasts, which is one more move toward the democratization of



The New Age of Procedural Texturing, Fig. 17 Bitmap2Material™ by Allegorithmic™ uses an image as input to procedurally generate a full-digital material (See Allegorithmic et al. 2003)

a



"Voronoi fishing net fractal" texture, the result of an iterative process

b

```
(Show (let [voronoi1 (voronoi :points 32)]
  (fractal
    :while (v- 0.97 (voronoi1-function
            (v- 1 (v* (vdivide (v- y x) y) (vdivide (v- z x) z)))
    :voronoi voronoi1))
    :update (v+ (v* pos 2) pos)
    :result (vdivide 3 (v+ 3 'i))
    :max-iterations 4)) 512 512
```

The generation code for the " Voronoi fishing net" textrure

The New Age of Procedural Texturing, Fig. 18 The "Voronoi fishing net fractal" texture on the left is the result of an iterative process. Advances in computational power now allow for such techniques to be used in production (Extract from Creative Clojure; see Creative Clojure n.d.)

procedural texturing. Finally, these tools are not limited or "exclusive" (in their approach) by design and embrace a novel view of procedural texturing and propose new techniques and approaches (see next section).

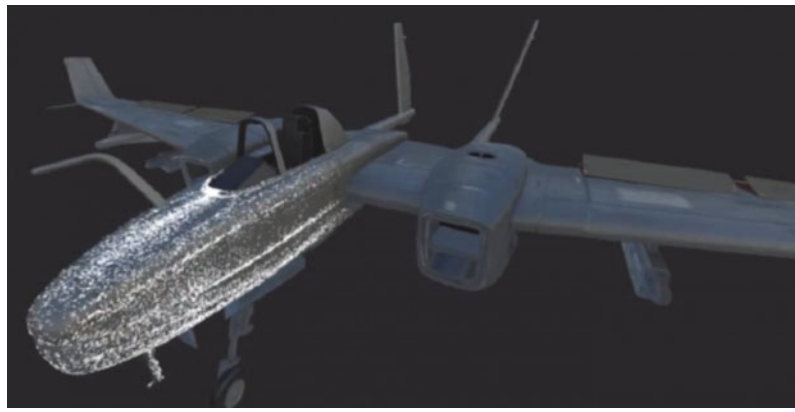
New Techniques and Tools

Maybe the most important point made in the past years by the creators of procedural texturing tools is the fact that the process has to be *hybrid*. Artists and developers alike do not want to "take on a side" anymore, whether to go full procedural or full manual. Procedural techniques, as we have seen, can now be utilized practically, and it is up to the artists to choose the technique they want to use for the particular task they have to complete. Modern tools allow for a hybrid approach, proposing procedural techniques that complement traditional hand-painting features, such as Allegorithmic™ Substance Painter™ (see Allegorithmic et al. 2003 and Fig. 16).

Other techniques have been largely improved in the recent years, adding to the arsenal of options to the artists. Techniques such as image-based texture synthesis are now widely used, and tools like Allegorithmic™ Bitmap2Material™ (see Allegorithmic et al. 2003 and Fig. 17) or more recently Artomatix™ (see Artomatix n.d.) are procedural-based tools largely used in production.

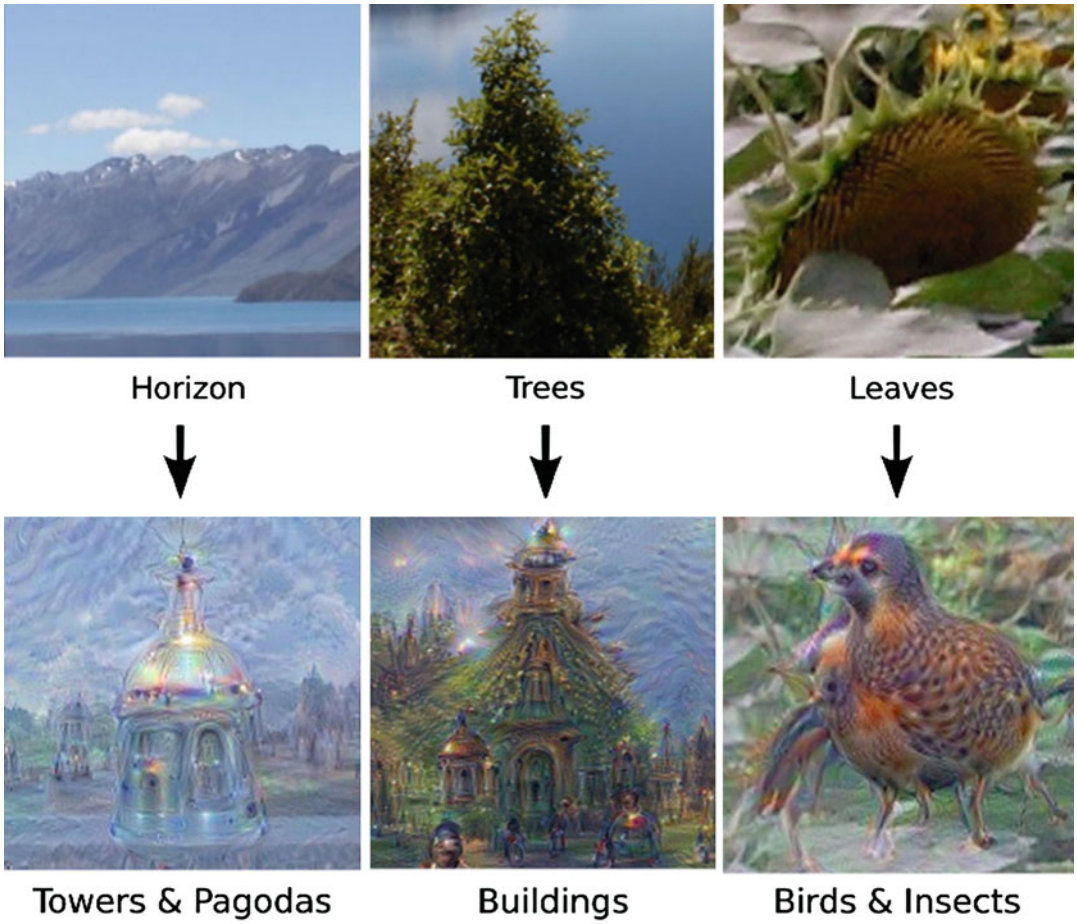
Iterative generation techniques (see, for instance, Fig. 18) have also been made practical, especially thanks to the advances in computational power. Instead of taking a long time to render (for each iteration to go through), these procedures can now be quasi real time, allowing artists to use a "trial and error" creative approach while modifying the parameters of the process in use.

Also worth noting here, and very much aligned with the idea of hybrid approaches mentioned above, Allegorithmic™ recently introduced a procedural brush system in which a particle simulation algorithm is utilized to paint over a surface, while the user controls various parameters that define the behavior of the particles, as well as the position at which the particles are spawned and directed (see Figs. 19 and 20).



The New Age of Procedural Texturing, Fig. 19 A particle simulation system is being used in Allegorithmic™ Substance Painter™ to give artists new procedural-based texture creation tools. The particles in *white* are "thrown" at the plane's nose, and, following a certain behavior, these particles will flow against the structure in a realistic way and leave dirt traces in the textures wrapped onto the plane, where they are supposed to appear (see Allegorithmic et al. 2003)

The New Age of Procedural Texturing, Fig. 20 Most of the textures on this character make use of the particle-based procedural brushes available in Allegorithmic™ Substance Painter™ (see Allegorithmic et al. 2003). Image by Christophe Desse, model by Olivier Couston. See Desse n.d.)



The New Age of Procedural Texturing, Fig. 21 The images or textures at the bottom have been "dreamt" by an algorithm developed at Google Research™. Advances in machine learning and neural networks will lead to novel procedural techniques and more effective manipulation of procedural techniques by computers and artists (See Google Research n.d.)

Finally, we can cite an area of research which will lead to more advances in procedural texturing: *machine learning* and the latest developments in recurring neural networks, as illustrated on Fig. 21 (see Google Research n.d.). These techniques will help both in producing new procedural techniques, derived from the experience and knowledge of the artists sharing their work and work process at a large scale (large enough so that algorithms can *learn* from it), as well as in the estimation of meaningful parameter spaces for a given procedural technique.

Conclusion

In this entry we have been shedding some light on what can reasonably be called a new age for procedural texturing. Procedural texturing, in itself, is a technique more than 30 years old that can have a lot of benefits but has been only very lightly used in production compared to traditional techniques. Due to major advances in computational power, to the appearance of dedicated, user-friendly tools, and to a pragmatic use of various, available techniques by

artists, today's production studios are embracing procedural texturing at a scale that has never been witnessed before. In many ways, this age is only beginning, and we predict we will see a lot more advances in this field in the years to come.

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The Sims Franchise, a Retrospective of Racial Representation and Skin Tones

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Synonyms

Life simulation game

Definitions

Life simulation game: Life simulation games usually have a focus on gameplay that allows players to have meaningful and complex interactions with the world around them. This interaction with the game's world usually addresses common life themes, such as farming, fishing, NPC social interaction, resource gathering, money-making, and many other themes found in day-to-day life.

History

The Sims franchise is a staple of life simulation games. Ever since the first game was released on February 4, 2000, the franchise has been extremely popular (Nutt and Railton 2003). The game started out with presets of clothing and shoes, three skin tones, five personality traits, two ages, and two genders. The first game in the series did not allow for much representation for gamers to express their individuality. As Albrechtslund (2007) puts it: "a successful life in *The Sims* [...is...] tied to a certain way of living both in gameplay and game representation."

With the popularity of the first game, Electronic Arts released *The Sims 2* on September 14, 2004. The game had changes both in design and game mechanics. The developer team, Maxis, has added new life stages to the CAS (Create-a-Sim, the interface where you design your sim), but the game still lacked considerable representation options. The second installment did add a new skin tone which brings it up to four from the previous three skin tones in the first game. The game also still only had two genders. The second installment also added a new feature to appearance which was the ability to change body mass, but there were only two options and players could not customize them. The hair given in the base game could be mixed and matched with any shirt, undergarment, and shoes. The hair additions had more diversity than the game before but became a discussion point for the future installment of the game (Griebel 2006).

The third installment in the franchise gave the game a huge facelift. *The Sims 3* was released on June 2, 2009. Like the second installment, there were changes in the game design and mechanics. The CAS options included three undertones for skin and had a slider so players could choose how dark or light the skin would be on their Sims. These new skin tone options enabled players to create sims that can be more of a faithful representation of themselves in the base game. The sliders were not just an option for the skin, but also to decide the body weight, muscle tone, and muscle definition for all genders, and breast size for females. The majority of the hair additions that came with the base game tended to be modeled from the Caucasian hair styles. This added to the discussions around the game not having more diverse options for players to represent themselves (liv3rpoolfan08 2009; siren2 2009).

The fourth installment of *The Sims 4* was released on May 6, 2013, and the game was completely different from the previous ones (McElroy 2014). This was the installment that completely changed the game design and mechanics from *The Sims 3*. There were mass improvements to the CAS features. Players could adjust the Sims bodies by dragging the features they wanted to change. There were, again, sliders for body weight and muscle mass/tone. However, there was a reversal on the skin tone options. Unlike the third installment, *The Sims 4* featured only a few numbers of skin tone swatches. The hair additions in the base game were also limited and still seem like they were modeled after the Caucasian hair styles. In the past couple of years, *The Sims 4* has had updates, added more skin tones and more hair additions to the base game. The game gave the player the ability to dress their sim, male or female, in masculine or feminine clothing. Other options were based on whether a Sim can or cannot become pregnant or whether the Sim can use the toilet standing or not. *The Sims* team has updated the game to include more items for different cultures, especially Diwali (SimGuruDrake 2017). Another big culture feature was clothing and architecture inspired by the Muslim religion (EA 2019).

The Sims franchise with the fourth installment motto was, "Unleash your imagination and create a unique world of Sims that's an expression of you! Explore and customize every detail from Sims to homes, and much more" (EA, n.d.). With this motto, players should feel like they should be represented, but many players have voiced out that they do not feel as represented. An identity they left out is that of representation of African American simmers (simmer is a self-assigned name for the members of the fanbase of the franchise).

African American simmers have voiced that the darker skin tones the game offers are ashy and there are no options for even darker tones (Jackson 2020). Although, this discrepancy was called out since the game was released, it also does not stop there. African American simmers have also dealt with the issues of poor texture quality of the afro hair. The hair represented in the game, like the ones before, still seemed like they are modeled after the European-descent-styled hairs.

A way for these types of simmers to express themselves is to use custom content (Sihvonen 2011). Custom content are objects that simmers create and post online for other simmers to

download. The addition of adding CC (custom content) to the Sims game means that those files take up space on a player's computer. Simmers are voicing their concern that players should not have to download CC just to be able to express themselves, but rather have items already in the game. These are the issues many simmers want fixed, and the team responded by saying "[...] in December, we'll be rolling out at least a hundred new skin tone swatches... with a particular emphasis on darker skin tones" (EA 2020a). Additionally, the aforementioned newsletter revealed that a slider will be featured on all swatches of skin tones which adds a further modification element.

Finally, in December 2020 holiday season, The Sims released the promised update that contains "100+ new skin tones, customization sliders for skin tones and makeup, and three improved base game hairstyles" (EA 2020b). The update came with sliders to adjust the light to dark value of each skin tone as well as a filter that categorizes the skin tones as warm, cool, or neutral.

Competition

The franchise has been ahead of the game when it comes to life simulation, but now there are indie games in production that could soon change the market of life simulation games. These games were especially highlighted in comparison due to the franchise's poor response rate to answer for the issues that the fan base voices.

One of the games that has made the Sims community excited is *Paralives*. The indie developers expanded the excitement by releasing a video of color customization which uses a color wheel on their news page and YouTube channel (Paralives, n.d.). With the color wheel, players of *Paralives* can customize their para's (A para is the *Paralives* equivalent of a sim.) hair color to whatever they want. With this feature, the game introduced the players' options to even further express themselves by recreating their own hair color which excited the Sims community due to the fact that the third Sims game introduced the color wheel which was removed in *The Sims 4*.

Another game reveal was the look of the game characters posted on their YouTube channel and *Paralives* news page. In *Paralives,* the human-like characters are called parafolks or para, like the characters in *The Sims* franchise are called sims. The equivalent of CAS in *Paralives* is *Paramaker*. Both the indie game and the fourth Sims game have similar features in their CAS. In Paramaker, players are able to change the overall shape and size of their characters' look, but the one mechanic that did not exist in *The Sims* was the option to change the height of the parafolks. This is a mechanic *The Sims* franchise never introduced to the game although simmers have the option to download a mod created by another Sims fan. Another feature that expands upon identity is the name customization that the game will have. Players have the option to give their parafolk a nickname and even a middle name. To represent those in some East Asian cultures, the team added the mechanic to have the option to flip the first and last name. The team is still thinking about more options like an artist/stage name and titles for parafolk.

As of November 2020, the indie game *Paralives* is far from being released since it is still in the early stage of development. So far, the game is attracting a wide amount of attention especially from the Sims community. This game provides game mechanics that the Sims community members have been wishing for since the third game.

Another indie game that recently drew attention is *Little Sim World*. On the game's official Twitter, an image of the character creation was shared that had a section showing the game's skin tones (@LittleSimWorld 2020). In the image, there are only ten selections. Following a review by a popular Sims YouTuber Plumbella (2020), *Little Sim World* added a slider for skin tone color. With the attention drawn to the issue, the indie team listened and added an element that would make all players able to find their own skin color in a short time. In comparison, it took years for the Sims team to address the skin tone issues. In this

light, smaller indie games seemingly have more opportunities to address these issues since they do not have to worry about longer corporate processes. The development team for Sims is under the name Maxis but is owned by Electronic Arts. This may result in the Sims development team not having as many creativity liberties as indie companies.

Little Sim World also introduced the identity of different genders. The game has the option of male and female but also includes nonbinary, transgender, intersex, and more. This option opens the doors for players to make any kind of character they want. Going along with the gender options, the game also allows romance between any characters, no matter the gender. *Paralives* also has this option but has not gone into more detail on their website or YouTube. *Paralives* introduced another parafolk named Sebastian who was openly revealed as being gay with his partner only being known by the name Lucas. *The Sims* franchise is not opposed to same-sex marriages but has not placed same-sex households in their game until more recently. *The Sims* does not give the vast amount of options to players like *Little Sim World*. Although players can create whatever gender they want in the Sims, the Sims themselves will not "identify" as that gender unless they use an outside mod.

With all of the options that indie games are providing to players in life simulation games, the market has the potential to change. When comparing *Paralives* and *Little Sim World* to *The Sims,* there are many similarities and differences. The indie games allow players to fully recreate themselves with very little limitations so far in their development process without the use of CC or mods.

With the Black Lives Matter movement and the growing acceptance of diverse identities, the staple of basic identity needs is coming to light, especially with life simulation games. *The Sims* is the most popular life simulation game from the time it was released. However, due to its slow adaptation, new indie games may have the upper hand by developing more options that offer more basic identity needs than *The Sims*. With new competition, *The Sims* franchise may need to adjust to the potentially new market to help stay in touch with players.

Cross-References

- ▶ Cross-Cultural Game Studies
- ▶ Game Prosumption
- ▶ Player-Avatar Link: Interdisciplinary Embodiment Perspectives

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Theory of Minkowski-Lorentz Spaces

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Synonyms

Canal surface; Circles space; Spheres space

Definitions

Introduction of Minkowski-Lorentz spaces to simplify Euclidean 2- or 3-dimensional problems.

Introduction

In this entry, the authors propose a survey on Minkowski-Lorentz spaces which are a generalization of the space-time used in Einstein's theory, equipped of the nondegenerate indefinite quadratic form

$$\mathcal{Q}_M\left(\vec{u}\right) = x^2 + y^2 + z^2 - c^2t^2$$

where (x,y,z) are the spacial components of the vector $\vec{u}$ and t is the time component of $\vec{u}$ and c is the constant of the speed of light. Computer Graphics computations involving families of circles or spheres are simplified in this space. One can note that a canal surface of the usual 3D Euclidean affine space is represented in the suitable Minkowski-Lorentz space by a curve. Moreover, in order to realize a G^1-blend between two canal surfaces, it is enough to make a G^1 join between two curves. From an affine Euclidean space $\mathscr{E}_n$ of dimension n where its usual value in Computer Graphic equals to 2 or 3, the authors define two Minkowski-Lorentz spaces of dimension $n+2$: the affine space $L_{n+1,1}$ and the vector space $\overrightarrow{L_{n+1,1}}$. The Minkowski-Lorentz space of dimension $n+2$ contains a n-dimensional paraboloid isometric to the affine Euclidean space $\mathscr{E}_n$. Moreover, an Alexandroff compactification of the affine Euclidean space $\mathscr{E}_n$ in the Minkowski-Lorentz space of dimension $n+2$ permits to develop some innovative general algorithms where the point at infinity of $\mathscr{E}_n$ is considered as a point of $\mathscr{E}_n$.

Planes, spheres, circular cylinders, and revolution cones are the basement of most computer aided software or 3D creation software. These main shapes or surfaces used in such background are easy to handle. The rapid access to their definition is due to the quadratic representation in terms of implicit equations or parametric representations. In addition the modeling geometric software need easy ways to join these elementary surfaces. One solution is the use of Minkowski-Lorentz space. The canal surfaces including Dupin cyclides, which contain tori, circular cylinders, and circular cones thanks to Alexandroff compactification, are joined by the plunge of the 3D space into a five dimensional space where the Dupin cyclides are mapped in quadratic rational Bézier curves. The G^1-join between spheres and

cylinders is completed in the new space by the G^1-join between two conics arcs. The Hugo robot (Foufou and Garnier 2004) representation can be based of all the previous elements and the join technic.

This entry presents the same formalism to manipulate families of circles or families of spheres. So a 2-sphere of $\mathscr{E}_3$ is the usual sphere, whereas a 1-sphere of $\mathscr{E}_2$ is a circle. A hyperplane is a plane in $\mathscr{E}_3$ and a line in $\mathscr{E}_2$. The $n-1$-dimensional unit sphere of the Minkowski-Lorentz space $L_{n+1,1}$ is the set representing $n-1$-spheres of the affine Euclidean space $\mathscr{E}_n$. Some uses of the Minkowski-Lorentz space $L_{4,1}$ can be found in Langevin et al. (2015) where a Dupin cyclide is built from three contact conditions or in Garnier et al. (2017) where a seahorse (Fig. 1) is built using G^1-joins between canal surfaces. These canal surfaces are computed using rational quadratic Bézier curves with mass points, the reader can refer to the articles (Garnier and Bécar 2016; Bécar 1997; Fiorot and Jeannin 1989, 1992; Goldman 2002).

Minkowski-Lorentz Spaces

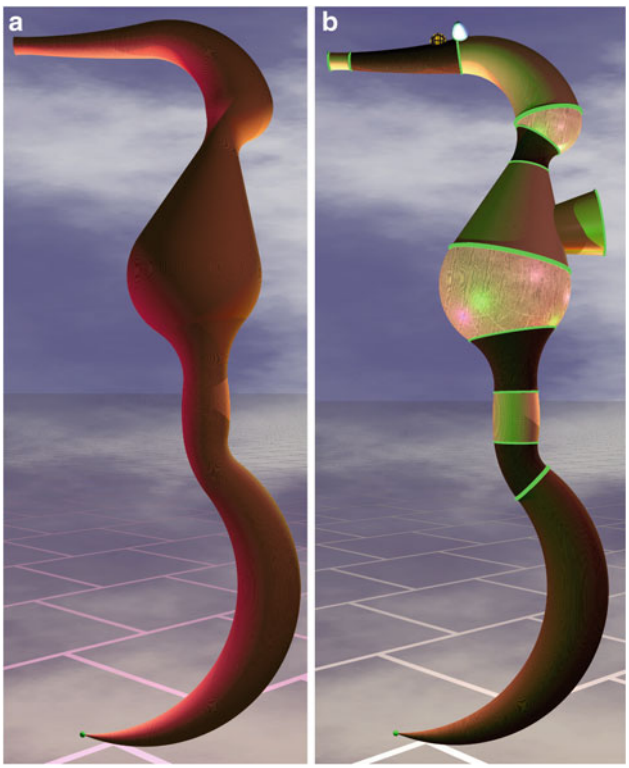
To simplify the manipulations of a family of $n-1$-spheres in $\mathscr{E}_n$, two $n+2$-dimensional spaces are introduced:

- An affine space $L_{n+1,1}$
- A vector space $\overrightarrow{L_{n+1,1}}$

Let $\left(\overrightarrow{e_i}\right)_{i\in[\![1,n]\!]}$ be an orthonormal basis for the usual Euclidean dot product of $\mathscr{E}_n$.

Definition 1 *Minkowski-Lorentz space associated to* $\mathscr{E}_n$

The Minkowski-Lorentz vector space associated to the Euclidean vector space $\overrightarrow{\mathscr{E}_n}$ *is*



Theory of Minkowski-Lorentz Spaces, Fig. 1 A seahorse modelled by G^1 blends of canal surfaces, each surface is represented by a rational quadratic Bézier curve in the Minkowski-Lorentz space. The join between two Bézier curves is G^1. (**a**) The seahorse without the dorsal fin. (**b**) The whole seahorse

$$\overrightarrow{L_{n+1,1}} = \overrightarrow{\mathbb{R}} \times \overrightarrow{\mathscr{E}_n} \times \overrightarrow{\mathbb{R}}$$

with the orthogonal basis $\left(\overrightarrow{e_-}, \overrightarrow{e_1}, \ldots, \overrightarrow{e_n}, \overrightarrow{e_+}\right)$ *equipped with the following Lorentz form, denoted* $L_{n+1,1}$ *or* $\blacksquare$, *defined as follow*

$$\begin{cases} \overrightarrow{e_-} \blacksquare \overrightarrow{e_-} = \overrightarrow{e_-}^2 = -1 \\ \forall i \in [\![1, n]\!] \cup \{+\} \overrightarrow{e_i} \blacksquare \overrightarrow{e_i} = \overrightarrow{e_i}^2 = 1 \end{cases}$$

The Minkowski-Lorentz affine space associated to the Euclidean affine space $\mathscr{E}_n$ *is defined by the point* O_{n+2} *and the Minkowski-Lorentz vector space* $\overrightarrow{\mathrm{L}_{n+1,1}}$. *All the coordinates of* O_{n+2} *are equal to zero.*

Using the point O_{n+2}, there is a one-to-one mapping between the vector space $\overrightarrow{\mathrm{L}_{n+1,1}}$ and the affine space $\mathrm{L}_{n+1,1}$

$$\forall\ \vec{u} \in \overrightarrow{\mathrm{L}_{n+1,1}}, \exists! M \in \mathrm{L}_{n+1,1} \mid \overrightarrow{O_{n+2}M} = \vec{u}$$

and

$$\forall M \in \mathrm{L}_{n+1,1}, \exists!\ \vec{u} \in \overrightarrow{\mathrm{L}_{n+1,1}} \mid \vec{u} = \overrightarrow{O_{n+2}M}$$

The point O_{n+2} is the origin of the Minkowski-Lorentz affine space $\mathrm{L}_{n+1,1}$.

The nondegenerate indefinite quadratic form associated to the Lorentz form is denoted $\mathscr{Q}_{n+1,1}$, its signature is $(n+1,1)$, and one can note that

$$\forall\ \vec{u} \in \overrightarrow{\mathrm{L}_{n+1,1}}\ \ \mathscr{Q}_{n+1,1}\left(\vec{u}\right) = \vec{u} \blacksquare \vec{u} = \vec{u}^2 \quad (1)$$

In order to simply the mathematical computations, the new basis $\left(\overrightarrow{e_o}, \overrightarrow{e_1}, \ldots, \overrightarrow{e_n}, \overrightarrow{e_\infty}\right)$ is introduced where

$$\begin{cases} \overrightarrow{e_0} = \overrightarrow{e_-} - \overrightarrow{e_+} \\ \overrightarrow{e_\infty} = \frac{1}{2}\left(\overrightarrow{e_-} + \overrightarrow{e_+}\right) \end{cases}.$$

and, in $\left(\overrightarrow{e_o}, \overrightarrow{e_1}, \ldots, \overrightarrow{e_n}, \overrightarrow{e_\infty}\right)$, the expression of the Lorentz form is obtained from

$$\begin{cases} \overrightarrow{e_o}^2 = \overrightarrow{e_\infty}^2 = 0 \\ \overrightarrow{e_i} \blacksquare \overrightarrow{e_o} = \overrightarrow{e_i} \blacksquare \overrightarrow{e_\infty} = 0 \\ \overrightarrow{e_i} \blacksquare \overrightarrow{e_j} = \delta_{ij} \\ \overrightarrow{e_o} \blacksquare \overrightarrow{e_\infty} = -1 \end{cases}. \quad (2)$$

where $(i, j) \in [\![1, n]\!]^2$ and δ_{ij} is the Kronecker Delta. The basis $\left(\overrightarrow{e_o}, \overrightarrow{e_1}, \ldots, \overrightarrow{e_n}, \overrightarrow{e_\infty}\right)$ is not an orthogonal basis given that

$$\begin{aligned} \overrightarrow{e_o} \blacksquare \overrightarrow{e_\infty} &= \frac{1}{2}\left(\overrightarrow{e_-} - \overrightarrow{e_+}\right)\left(\overrightarrow{e_-} + \overrightarrow{e_+}\right) \\ &= \frac{\overrightarrow{e_-}^2 - \overrightarrow{e_+}^2}{2} = \frac{-1-1}{2} = -1 \end{aligned}$$

The expression of the Lorentz form in this new basis follows. Let $\vec{u}(x_o, x_1, \ldots, x_n, x_\infty)$ and $\vec{v}(y_o, y_0, \ldots, y_n, x_\infty)$ be two vectors of $\overrightarrow{\mathrm{L}_{n+1,1}}$ then

$$\begin{aligned} \mathscr{L}_{n+1,1}\left(\vec{u}, \vec{v}\right) &= \vec{u} \blacksquare \vec{v} \\ &= \sum_{i=1}^{n} x_i y_i - x_o y_\infty - x_\infty y_o \quad (3) \end{aligned}$$

In the following of this section, three fundamental sets of points in the Minkowski-Lorentz affine space $\mathrm{L}_{n+1,1}$ are defined.

The Light Cone or the Null *n* + 1-Pseudosphere C_l

As the quadratic Lorentz product is a nondegenerate indefinite quadratic form, there exists some isotropic vectors. These nonnull vectors are called light-like vectors and satisfy

$$\vec{u}^2 = \vec{u} \blacksquare \vec{u} = 0$$

Thus, an isotropic vector is orthogonal to itself. Three types of vectors can be defined (Table 1).

So, a set with a particular shape is introduced: a null $n+1$-pseudo-sphere which looks like a $n+1$-dimensional cone. A position vector $\vec{m}$ defines the point m via the relation $\vec{m} = \overrightarrow{O_{n+2}m}$.

Definition 2 *The light cone C_l which is a null $n+1$-pseudo-sphere*

The light cone of the Minkowski-Lorentz affine space $L_{n+1,1}$ is the set C_l of isotropic position vectors i.e.,

$$C_l = \left\{ m \in L_{n+1,1} | = \overrightarrow{O_{n+2}m}^2 = 0 \right\} \tag{4}$$

From Formula (4), one can deduce that the distance between O_{n+2} and any point m of C_l equals zero, and the light-cone is a null-sphere of center O_{n+2} (Figs. 2 and 5). In the following of this entry, a point of $\mathscr{E}_n$ is denoted with a capital letter, its representation in the Minkowski-Lorentz is denoted with the same small letter (a vector in $\overrightarrow{L_{n+1,1}}$ or a point in $L_{n+1,1}$).

Using the reference frame $\left(O_{n+2}, \overrightarrow{e_-}, \overrightarrow{e_1}, \ldots, \overrightarrow{e_n}, \overrightarrow{e_+}\right)$, the equation of the light cone is given by

$$-x_-^2 + \sum_{i=1}^{n} x_i^2 + x_+^2 = 0 \tag{5}$$

where $(x_-, x_1, \ldots, x_n, x_+)$ are the coordinates of a point of $L_{n+1,1}$. Alternatively, using the reference frame $\left(O_{n+2}, \overrightarrow{e_o}, \overrightarrow{e_1}, \ldots, \overrightarrow{e_n}, \overrightarrow{e_\infty}\right)$, the equation of the light cone becomes

$$\sum_{i=1}^{n} x_i^2 - 2x_o x_\infty = 0 \tag{6}$$

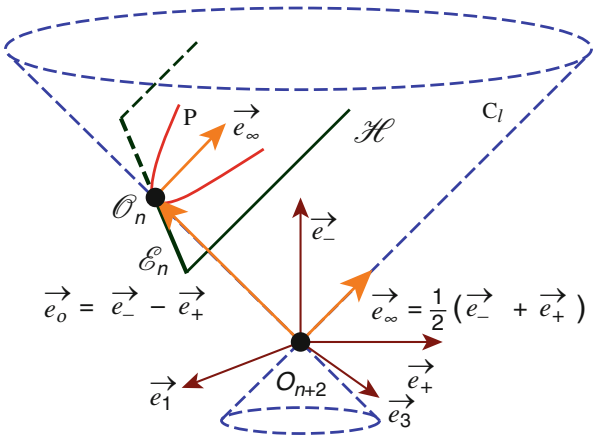
Now, a model of $\mathscr{E}_n \cup \{\infty\}$ in the Minkowski-Lorentz affine space $L_{n+1,1}$ is presented.

Theory of Minkowski-Lorentz Spaces, Table 1 Definition of the three types of vectors the Minkowski-Lorentz vector space $\overrightarrow{L_{n+1,1}}$ using the quadratic form $\mathscr{Q}_{n+1,1}$ given in Formula (1)

Type of the vector	Vector $\vec{u}$
Space-like	$\mathscr{Q}_{n+1,1}\left(\vec{u}\right) = \vec{u}^2 > 0$
Time-like	$\mathscr{Q}_{n+1,1}\left(\vec{u}\right) = \vec{u}^2 < 0$
Light-like	$\mathscr{Q}_{n+1,1}\left(\vec{u}\right) = \vec{u}^2 = 0$

The Paraboloid P Which Generates an Alexandroff Compactification of $\mathscr{E}_n$, Isometric to $\mathscr{E}_n$

Let $\mathscr{O}_n$ be the point defined by



Theory of Minkowski-Lorentz Spaces, Fig. 2 The $n+1$-dimensional light cone C_l, the $n+1$-dimensional affine hyperplane H, and the n-dimensional paraboloid P isometric to E_n

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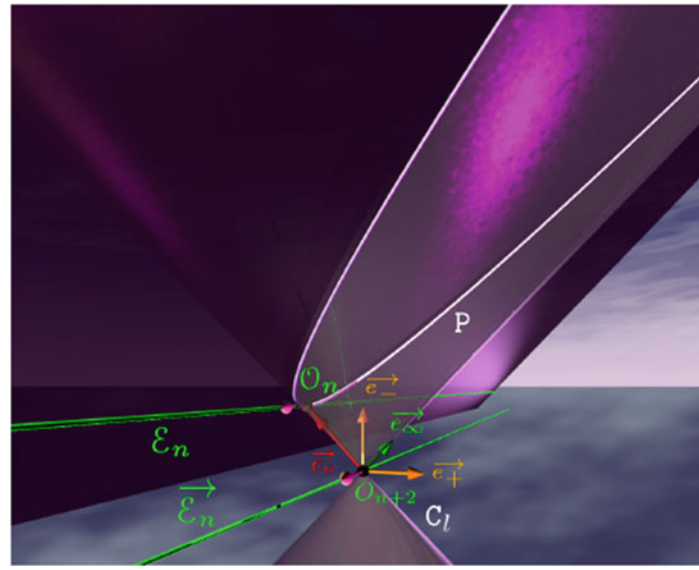

Theory of Minkowski-Lorentz Spaces, Fig. 3 The light cone C_l, the hyperplane $\mathscr{H}$, and the paraboloid P isometric to $\mathscr{E}_n$ and an Alexandroff compactification of $\mathscr{E}_n$ is $P \cup \{\overrightarrow{e_\infty}\}$. The green lines illustrate the Euclidean vector space $\overrightarrow{\mathscr{E}_n}$ and the Euclidean affine space $\mathscr{E}_n$

$$\overrightarrow{O_{n+2}\mathscr{O}_n} = \overrightarrow{e_o}$$

and $\mathscr{O}_n$ is the origin of the embedding $\{1\} \times \mathscr{E}_n \times \{0\}$ of the Euclidean affine space $\mathscr{E}_n$ into the Minkowski-Lorentz affine space $L_{n+1,1}$, i.e., if $(x_1,\ldots,x_n)$ are the coordinates of a point M in $\mathscr{E}_3$. The point M can be mapped to the point of coordinates $(1,x_1,\ldots,x_n,\ 0)$ in the reference frame $\left(O_{n+2}, \overrightarrow{e_o}, \overrightarrow{e_1}, \ldots, \overrightarrow{e_n}, \overrightarrow{e_\infty}\right)$. This map is one-to-one between $\mathscr{E}_3$ and $\{1\} \times \mathscr{E}_n \times \{0\}$. Now, the point $\mathscr{O}_n$ is the origin of the Euclidean affine space $\mathscr{E}_n$.

Let $\mathscr{H}$ be the affine hyperplane of $L_{n+1,1}$ defined by:

- The origin $\mathscr{O}_n$ of the Euclidean affine space $\mathscr{E}_n$
- The n space–like vectors $\overrightarrow{e_1}, \ldots, \overrightarrow{e_n}$ of the Euclidean vector space $\overrightarrow{\mathscr{E}_n}$
- The light-like vector $\overrightarrow{e_\infty}$

Let M be a point of $\mathscr{H}$, its coordinates are $(x_1,\ldots,x_n,\ x_\infty)$ in the reference frame $\left(\mathscr{O}_n, \overrightarrow{e_1}, \ldots, \overrightarrow{e_n}, \overrightarrow{e_\infty}\right)$, i.e.,

$$\overrightarrow{\mathscr{O}_n M} = \sum_{i=1}^{n} x_i \overrightarrow{e_i} + x_\infty \overrightarrow{e_\infty}$$

and then

$$\overrightarrow{\mathscr{O}_n M}^2 = \sum_{i=1}^{n} x_i \underbrace{\overrightarrow{e_i}^2}_{=1} + \sum_{i=1}^{n} (x_i \times x_\infty) \underbrace{\overrightarrow{e_i} \cdot \overrightarrow{e_\infty}}_{=0} + x_\infty^2 \underbrace{\overrightarrow{e_\infty}^2}_{=0} = \sum_{i=1}^{n} x_i^2 \tag{7}$$

the restriction to $\mathscr{H}$ of the nondegenerate indefinite quadratic form $\mathscr{Q}_{n+1,1}$ is degenerate, its signature is $(n,0)$ (the dimension of $\mathscr{H}$ is $n + 1$). Moreover, the point M is identified with $M_n\ (x_1,\ldots,x_n)$ of $\mathscr{E}_n$ and one can recognize the expression of the Euclidean scalar product of $\overrightarrow{\mathscr{E}_n}$ i.e.,

$$\overrightarrow{\mathscr{O}_n M_n}^2 = \sum_{i=1}^{n} x_i^2$$

Now, the paraboloid P can be defined.

Definition 3 *Paraboloid P*

The paraboloid P is the section of the light cone by the hyperplane $\mathscr{H}$, i.e.,

$$P = C_l \cap \mathscr{H}$$

Figure 2 shows the construction of the paraboloid P in the Minkowski-Lorentz affine space $L_{n+1,1}$.

These objects are linked thanks to the following theorem:

Theorem 1 *The equation of the paraboloid P is given by*

$$\begin{cases} x_o - 1 &= 0 \\ \sum_{i=1}^{n} x_i^2 - 2x_o x_\infty &= 0 \end{cases} \tag{8}$$

and the paraboloid P is isometric to the embedding $\{1\} \times \mathscr{E}_n \times \{0\}$ *of the Euclidean affine space* $\mathscr{E}_n$ *in the Minkowski-Lorentz affine space* $L_{n+1,1}$.

The paraboloid is a representation of the Euclidean affine space $\mathscr{E}_n$ *in the Minkowski-Lorentz affine space* $L_{n+1,1}$. *The representation of a point M* $(x_1,\ldots,x_n)$ *of* $\mathscr{E}_n$ *is the point*

$$m\left(1, x_1, \ldots, x_n, \frac{1}{2}\sum_{i=1}^{n} x_i^2\right)$$

with $\overrightarrow{O_{n+2}m}^2 = 0$.

Proof:

Formula (8) is obtained from:

- The equation of the hyperplane $\mathscr{H}$, that is, $x_0 - 1 = 0$
- The equation of the light cone C_l, that is, $\sum_{i=1}^{n} x_i^2 - 2x_o x_\infty = 0$

A one-to-one relationship between a point M $(x_1,\ldots,x_n)$ of $\mathscr{E}_n$ and the point $m(1,x_1,\ldots,x_n, x_\infty)$ is given by

$$\begin{aligned} \overrightarrow{O_{n+2}m} &= \overrightarrow{O_{n+2}\mathscr{O}_n} + \overrightarrow{\mathscr{O}_n M} + x_\infty \overrightarrow{e_\infty} \\ &= \overrightarrow{O_{n+2}\mathscr{O}_n} + \sum_{i=1}^{n} x_i \vec{e_i} + x_\infty \overrightarrow{e_\infty} \\ &= \vec{e_o} + \sum_{i=1}^{n} x_i \vec{e_i} + x_\infty \overrightarrow{e_\infty} \end{aligned}$$

The point m belongs to P if and only if m belongs to the light cone C_l. Then

$$\overrightarrow{O_{n+2}m}^2 = \sum_{i=1}^{n} x_i^2 - 2 \times 1 \times x_\infty = 0$$

leads to

$$x_\infty = \frac{1}{2}\sum_{i=1}^{n} x_i^2 = \frac{1}{2}\overrightarrow{\mathscr{O}_n M}^2$$

and the coordinates of m are

$$\left(1, x_1, \ldots, x_n, \frac{1}{2}\sum_{i=1}^{n} x_i^2\right)$$

Conversely, the projection of a point $m\left(1, x_1, \ldots, x_n, \frac{1}{2}\sum_{i=1}^{n} x_i^2\right)$ onto the embedding $\{1\} \times \mathscr{E}_n \times \{0\}$ along the direction of $\overrightarrow{e_\infty}$ is

$$m_1(1, x_1, \ldots, x_n, 0)$$

witch represents the point M $(x_1,\ldots,x_n)$ of the Euclidean affine space $\mathscr{E}_n$.

With $n = 1$, Fig. 3 shows a 3D view of the embedding $\{1\} \times \mathscr{E}_n \times \{0\}$ of the Euclidean affine space $\mathscr{E}_n$ into the Minkowski-Lorentz affine space $L_{n+1,1}$.

Note that the vector space vector $\overrightarrow{e_\infty}^{\perp}$ orthogonal to the vector space defined by the $\overrightarrow{e_\infty}$ is equal to the $n-1$-dimensional vector space

$$\overrightarrow{e_\infty}^{\perp} = \vec{\mathscr{H}}$$

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and the authors recall that the vector $\overrightarrow{e_o}$ and $\overrightarrow{e_\infty}$ are not orthogonal. Now, the authors give the following remark:

Remark 1 *Representation of a point of* $\mathscr{E}_n$ *in* $L_{n+1,1}$

1. *Let M be a point of* $\mathscr{E}_n$
   (a) *Construction of* m_1 *defined by*

$$\overrightarrow{O_{n+2}m_1} = \overrightarrow{O_{n+2}\mathscr{O}_n} + \overrightarrow{\mathscr{O}_nM} = \overrightarrow{e_o} + \sum_{i=1}^{n} x_i \overrightarrow{e_i}$$

(b) *Construction of m defined by*

$$\overrightarrow{m_1m} = \frac{\sum_{i=1}^{n} x_i^2}{2} \overrightarrow{e_\infty} = \frac{\overrightarrow{\mathscr{O}_nM}^2}{2} \overrightarrow{e_\infty}$$

(c) *The representation of the point M of* $\mathscr{E}_3$ *is the light-like vector of the Minkowski-Lorentz vector space* $\overrightarrow{\mathrm{L}_{n+1,1}}$ *defined by*

$$\vec{m} = \overrightarrow{O_{n+2}\mathscr{O}_n} + \overrightarrow{\mathscr{O}_nM} + \frac{1}{2}\sum_{i=1}^{n} x_i^2 \overrightarrow{e_\infty}$$

$$= \overrightarrow{e_o} + \sum_{i=1}^{n} x_i \overrightarrow{e_i} + \frac{1}{2}\sum_{i=1}^{n} x_i^2 \overrightarrow{e_\infty}$$

i.e.,

$$\vec{m} = \overrightarrow{e_o} + \vec{M} + \frac{1}{2}\left\|\vec{M}\right\|^2 \overrightarrow{e_\infty} \tag{9}$$

where $\vec{M}$ *is the position vector defined by M in* $\overrightarrow{\mathscr{E}_n}$, i.e., $\vec{M} = \overrightarrow{\mathscr{O}_nM}$.

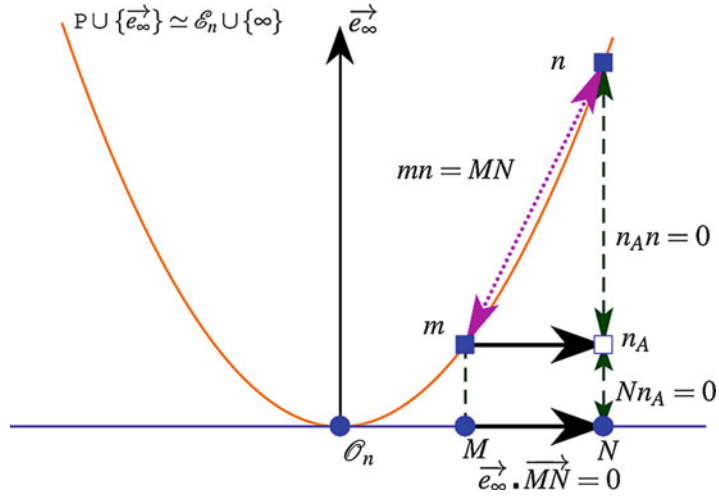
2. *The representation of the point at infinity* ∞ *of* $\mathscr{E}_n$ *is the light-like vector* $\overrightarrow{e_\infty}$.

A well-known Alexandroff compactification of the Euclidean affine space $\mathscr{E}_n$ is the hypersphere $\mathscr{S}_{n+1}$ in $\mathscr{E}_{n+1}$, and the north pole represents the point at infinity ∞ of $\mathscr{E}_n$. The following proposition offers Alexandroff compactification using the property that P is isometric to $\mathscr{E}_n$ making computations easier.

Proposition 1 *Alexandroff compactification of* $\mathscr{E}_n$

The set $P \cup \{\overrightarrow{e_\infty}\}$ *is an Alexandroff compactification of the Euclidean affine space* $\mathscr{E}_n$.

Figure 4 shows an Alexandroff compactification of the Euclidean affine space $\mathscr{E}_n$ and the isometry between $\mathscr{E}_n$ and the paraboloid P. Let M and N be two points of $\mathscr{E}_n \simeq \{1\} \times \mathscr{E}_3 \times \{0\}$. Let m and n be their representations on the paraboloid P, i.e., the point m (resp. n) is the intersection between P and the line defined



Theory of Minkowski-Lorentz Spaces, Fig. 4 Alexandroff compactification P ∪ $\{\overrightarrow{e_\infty}\}$ of the Euclidean affine $\mathscr{E}_n$ where the paraboloid P is isometric to the Euclidean affine $\mathscr{E}_n$

by the point M (resp. N) and the vector $\overrightarrow{e_\infty}$. Then

$$\overrightarrow{Mm}^2 = \overrightarrow{Nn}^2 = 0$$

The point n_A is defined as follows

$$\overrightarrow{mn_A} = \overrightarrow{MN}$$

The triangle mnn_A has two orthogonal segments ($[mn_A]$ and $[nn_A]$), using Pythagorean Theorem, it yields

$$\overrightarrow{mn}^2 = \overrightarrow{mn_A}^2 + 2\underbrace{\overrightarrow{mn_A}\cdot\overrightarrow{n_An}}_{0} + \underbrace{\overrightarrow{n_An}^2}_{0} = \overrightarrow{mn_A}^2 \quad (10)$$

which leads to

$$\begin{aligned}\overrightarrow{mn}\cdot\overrightarrow{e_\infty} &= \left(\overrightarrow{mn_A} + \overrightarrow{n_An}\right)\cdot\overrightarrow{e_\infty} \\ &= \underbrace{\overrightarrow{MN}\cdot\overrightarrow{e_\infty}}_{0} + \underbrace{\overrightarrow{n_An}\cdot\overrightarrow{e_\infty}}_{0} = 0 \end{aligned} \quad (11)$$

and any vector $\alpha\overrightarrow{AB} + \beta\overrightarrow{e_\infty}, (\alpha,\beta) \in \mathbb{R}^2$, is orthogonal to $\overrightarrow{e_\infty}$. The triangle mn_An is isosceles ($mn_A = mn$) and has two couples of orthogonal segments: the segments $[mn_A]$ and $[n_An]$ and the segments $[mn]$ and $[n_An]$.

A point of $\mathscr{E}_n$ is represented by a light-like vector in the Minkowski-Lorentz vector space $\overrightarrow{\mathrm{L}_{n+1,1}}$. Is the converse true?

The answer is given by:

Proposition 2 *Point defined by a light-like vector*

Let $\vec{m}(x_o, x_1, \ldots, x_n, x_\infty)$ be a nonnull light-like vector.

- *If $x_o = 0$, for all i in $[\![1, n]\!]$, $x_i = 0$ and the vector $\frac{1}{x_\infty}\vec{m} = \overrightarrow{e_\infty}$ represents the point at infinity of the Euclidean affine space $\mathscr{E}_n$.*
- *If $x_o \neq 0$, the vector $\frac{1}{x_o}\vec{m}$ represents the point*

$$M\left(\frac{x_1}{x_o}, \ldots, \frac{x_n}{x_o}\right)$$

of the Euclidean affine space $\mathscr{E}_n$.

The link between the Lorentz form of two light-like vectors and the distance between the corresponding points is given to end this paragraph.

Proposition 3 *Product of two light-like vectors*

Let M_0 and M_1 be two points of the Euclidean affine space $\mathscr{E}_n$.

Let $\overrightarrow{m_0}$ and $\overrightarrow{m_1}$ be two light-like vectors which represent the points M_0 and M_1.

Then

$$\overrightarrow{m_0}\cdot\overrightarrow{m_1} = -\frac{M_0M_1^2}{2} < 0$$

and

$$\overrightarrow{m_0}\cdot\overrightarrow{e_\infty} = -1$$

Proof: The system of equations

$$\begin{cases} \overrightarrow{m_0} = \vec{e_0} + \overrightarrow{M_0} + \dfrac{\overrightarrow{M_0}^2}{2}\overrightarrow{e_\infty} = \vec{e_o} + \overrightarrow{\mathscr{O}_nM_0} + \dfrac{\overrightarrow{\mathscr{O}_nM_0}^2}{2}\overrightarrow{e_\infty} \\ \overrightarrow{m_1} = \vec{e_0} + \overrightarrow{M_0} + \dfrac{\overrightarrow{M_1}^2}{2}\overrightarrow{e_\infty} = \vec{e_o} + \overrightarrow{\mathscr{O}_nM_1} + \dfrac{\overrightarrow{\mathscr{O}_nM_1}^2}{2}\overrightarrow{e_\infty} \end{cases}$$

leads to

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$$\overrightarrow{m_0}\blacksquare\overrightarrow{m_1} = \underbrace{\overrightarrow{e_o}^2}_{=0} + \underbrace{\overrightarrow{e_o}\blacksquare\overrightarrow{\mathscr{O}_n M_1}}_{=0} + \underbrace{\overrightarrow{\mathscr{O}_n M_0}\blacksquare\overrightarrow{e_o}}_{=0} + \overrightarrow{\mathscr{O}_n M_0}\bullet\overrightarrow{\mathscr{O}_n M_1} + \frac{1}{2}\left(\overrightarrow{\mathscr{O}_n M_0}^2 + \overrightarrow{\mathscr{O}_n M_1}^2\right)\overrightarrow{e_o}\blacksquare\overrightarrow{e_\infty}$$
$$= -\frac{1}{2}\left(\overrightarrow{\mathscr{O}_n M_0}^2 + \overrightarrow{\mathscr{O}_n M_1}^2 - 2\overrightarrow{\mathscr{O}_n M_0}\bullet\overrightarrow{\mathscr{O}_n M_1}\right) = -\frac{M_0 M_1^2}{2}$$

The computation of the second case gives

$$\overrightarrow{m_0}\blacksquare\overrightarrow{e_\infty} = \left(\overrightarrow{e_0} + \overrightarrow{M_0} + \frac{\overrightarrow{M_0}^2}{2}\overrightarrow{e_\infty}\right)\blacksquare\overrightarrow{e_\infty}$$
$$= \overrightarrow{e_o}\blacksquare\overrightarrow{e_\infty} = -1$$

It is fundamental that the light-like vectors are the representations of points of $\mathscr{E}_n$ since

$$\left(-\overrightarrow{m_0}\right)\blacksquare\overrightarrow{m_1} > 0$$

Space of Oriented $n-1$-Spheres Denoted Λ^{n+1}

The representation of an oriented $n-1$-sphere in the Minkowski-Lorentz space is given in Dorst et al. (2007).

Definition 4 *Representation of an oriented Euclidean sphere of $\mathscr{E}_n$*

Let S be an oriented $n-1$-sphere of $\mathscr{E}_n$ of center Ω and of algebraic radius ρ.

The representation of S is the point σ or the position vector $\vec{\sigma}$ defined by

$$\vec{\sigma} = \overrightarrow{O_{n+2}\sigma} = \frac{1}{\rho}\left(\vec{\omega} - \frac{1}{2}\rho^2\overrightarrow{e_\infty}\right)$$
$$= \frac{1}{\rho}\left(\overrightarrow{e_o} + \vec{\Omega} + \frac{1}{2}\left(\left\|\vec{\Omega}\right\|^2 - \rho^2\right)\overrightarrow{e_\infty}\right)$$
$$= \frac{1}{\rho}\left(\vec{\omega} - \frac{\rho^2}{2}\overrightarrow{e_\infty}\right) \tag{12}$$

where $\vec{\omega}$ represents the center Ω of the sphere.

The following theorem provides an important result:

Theorem 2 *Let σ or $\vec{\sigma}$ be the representation of an Euclidean $n-1$-sphere of $\mathscr{E}_n$ in the Minkowski-Lorentz space. Then*

$$\vec{\sigma}^2 = \overrightarrow{O_{n+2}\sigma}^2 = 1$$

Proof:

$$\vec{\sigma} = \overrightarrow{O_{n+2}\sigma}^2$$
$$= \frac{1}{\rho^2}\left(\overrightarrow{e_o} + \vec{\Omega} + \frac{1}{2}\left(\left\|\vec{\Omega}\right\|^2 - \rho^2\right)\overrightarrow{e_\infty}\right)^2$$
$$= \frac{1}{\rho^2}\left(\vec{\Omega}^2 + 2\frac{1}{2}\left(\left\|\vec{\Omega}\right\|^2 - \rho^2\right)\left(\overrightarrow{e_0}\blacksquare\overrightarrow{e_\infty}\right)\right)$$
$$= \frac{1}{\rho^2}\left(\vec{\Omega}^2 + \left(\left\|\vec{\Omega}\right\|^2 - \rho^2\right)(-1)\right)$$
$$= 1$$

In the same way, the representation of an oriented hyperplane of $\mathscr{E}_n$ in the Minkowski-Lorentz space is given Dorst et al. (2007).

Definition 5 *Representation of an oriented Euclidean hyperplane of $\mathscr{E}_n$*

Let $\mathscr{P}$ be an oriented hyperplane of $\mathscr{E}_n$, this orientation is defined by the unit vector $\vec{N}$.

The representation of $\mathscr{P}$ is the point π or the position vector $\vec{\pi}$ defined by

$$\vec{\pi} = \overrightarrow{O_{n+2}\pi} = -\vec{N} - \left(\vec{N}\bullet\vec{P}\right)\overrightarrow{e_\infty} \tag{13}$$

A quick calculation gives

$$\vec{\pi}^2 = \vec{N}^2 = 1$$

and in the following of this entry, a hyperplane of $\mathscr{E}_n$ is considered as a $n-1$-sphere. The last

fundamental surface of the Minkowski-Lorentz affine space $L_{n+1,1}$ can be presented.

Definition 6 *Representation of the Euclidean $n-1$-spheres of $\mathscr{E}_n$*

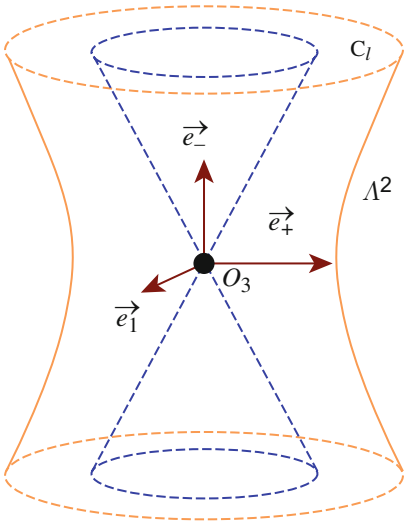
The representations of the oriented $n-1$-spheres of $\mathscr{E}_n$ belong to the unit sphere Λ^{n+1} of center O_{n+2} of the Minkowski-Lorentz affine space $L_{4,1}$ i.e.,

$$\Lambda^{n+1} = \left\{\sigma \in L_{n+1,1} | \ = \overrightarrow{O_{n+2}\sigma^2} = 1\right\} \tag{14}$$

If $n = 2$, Λ^3 is the space of circles of the Euclidean plane $\mathscr{E}_2$, whereas if $n = 3$, Λ^4 is the space of spheres of the 3D Euclidean space $\mathscr{E}_3$. Figure 5 shows Λ^2 in the 3-dimensional Minkowski-Lorentz affine space $L_{2,1}$. In the following of this entry, some constructions on Λ^n are made using Λ^2.

From Formulas (12) and (13), the representations of two oriented $n-1$-spheres (the centers are the same, the radii are opposite) S^+ and S^- of $\mathscr{E}_n$ are:

- Two unit opposite position vectors space $\vec{\sigma}^+$ and $\vec{\sigma}^-$ in the Minkowski-Lorentz vector $\overrightarrow{L_{n+1,1}}$
- Two points σ^+ and σ^- on Λ^{n+1} in the Minkowski-Lorentz affine space $Ln+1,1$, symmetric with respect to the point O_{n+2}



Theory of Minkowski-Lorentz Spaces, Fig. 5 The null sphere (i.e., the light cone) C_l of center O_3 and the unit sphere Λ^1 of center O_3

As the space of $n-1$-spheres is a surface of the Minkowski-Lorentz affine space $L_{n+1,1}$, the gradient of Λ^{n+1} at a point σ can be computed. The equation of Λ^{n+1} is given by

$$-x_-^2 + \sum_{i=1}^{n} x_i^2 + x_+^2 - 1 = 0$$

and the function f, of class $\mathscr{C}^1$, is introduced as follows.

$$\begin{array}{rccl} f: & L_{n+1,1} & \to & \mathbb{R} \\ & (x_-, x_1, \ldots, x_n, x_+) & \mapsto & -x_-^2 + \sum_{i=1}^{n} x_i^2 + x_+^2 - 1 \end{array}$$

The gradient of Λ^{n+1} at a point $\sigma(x_-, x_1, \ldots, x_n, x_+)$ is the vector

$$\overrightarrow{\nabla f}(x_-, x_1, \ldots, x_n, x_+)$$

defined by

$$d_{(x_-,x_1,\ldots,x_n,x+)} f(h_-, h_1, \ldots, h_n, h_+) = L_{n+1,1}\left(\overrightarrow{\nabla f}(x_-, x_1, \ldots, x_n, x_+), \vec{h}\right)$$

where the components of the vector $\vec{h}$ are $(h_-,h_1,\ldots,h_n,h_+)$. Note that the gradient depends on the Lorentz form

$$d_{(x_-,x_1,\ldots,x_n,x+)}f = \frac{\partial f}{\partial x_-}(x_-,x_1,\ldots,x_n,x_+)dx_- + \sum_{i=1}^{n}\frac{\partial f}{\partial x_i}(x_-,x_1,\ldots,x_n,x_+)dx_i + \frac{\partial f}{\partial x_+}(x_-,x_1,\ldots,x_n,x_+)dx_+$$

and

$$d_{(x_-,x_1,\ldots,x_n,x+)}f = -2x_-dx_- + \sum_{i=1}^{n}2x_idx_i + 2x_+dx_+$$

which leads to

$$d_{(x_-,x_1,\ldots,x_n,x+)}f(h_-,h_1,\ldots,h_n,h_+) = -2x_0h_0 + \sum_{i=1}^{n}2x_ih_i + 2x_+h_+$$

and the gradient is

$$\overrightarrow{\nabla f}(x_-,x_1,\ldots,x_n,x_+) = (2x_-,2x_1,\ldots,2x_n,2x_+) = 2\vec{\sigma} \quad (15)$$

As Λ^{n+1} is a sphere for the Lorentz product, Formula (15) is the same than the usual Euclidean formula.

The next section details that quadratic properties in $\mathscr{E}_n$ become linear in the Minkowski-Lorentz space.

Decreasing the Computation Degree

First, the conditions to determine if a point of $\mathscr{E}_n$ belongs to a given $n-1$-sphere are stated. Second, the conditions to determine the relative position of two $n-1$-spheres are given. The relation between two spheres will be used in the rest of this entry:

Definition 7 *Orthogonal spheres and relative power of two spheres*

For $i \in \{1,2\}$, let S*i be a $n-1$-sphere of center Ω_i and of radius ρ_i. The relative power $\chi_{S1,S2}$ of the two spheres S_1 and S_2 is equal to*

$$\chi_{S1,S2} = \Omega_1\Omega_2^2 - \rho_1^2 - \rho_2^2 \quad (16)$$

Moreover, the $n-1$-spheres S_1 and S_2 are orthogonal if

$$\chi_{S_1,S_2} = 0 \quad (17)$$

In fact, let A be a point of the nonempty set $S_1 \cap S_2$. The $n-1$ spheres S_1 and S_2 are orthogonal if $\Omega_1\,\Omega_2A$ is a right triangle and the segment $[\Omega_1\,\Omega_2]$ is the hypotenuse of the triangle $\Omega_1\,\Omega_2A$.

Relationship Between a Point and a $n-1$-Sphere

Four important results are given:

Theorem 3 *Relative position between a point and a sphere or a hyperplane*

Let S *be a $n-1$-sphere of $\mathscr{E}_n$, of center Ω, of radius ρ and let $\vec{\sigma}$ be its representation in the Minkowski-Lorentz vector space.*

Let $\mathscr{P}$ be a hyperplane of $\mathscr{E}_n$ passing through the point P_0, of unit normal vector $\vec{N}$ and let $\vec{\pi}$ be its representation in the Minkowski-Lorentz vector space.

Let $\vec{p}$ be the light-like vector in the Minkowski-Lorentz vector space which represents the point P of $\mathscr{E}_n$.

Then:

1. *The computation*

$$\vec{\sigma} \cdot \vec{p} = -\frac{1}{2\rho}\chi_S(P) = -\frac{1}{2\rho}\left(\Omega P^2 - \rho^2\right) \quad (18)$$

leads to

$$P \in S \Leftrightarrow \vec{\sigma} \cdot \vec{p} = 0 \quad (19)$$

2. *The computation*

$$\vec{\pi} \cdot \vec{p} = -\vec{N} \bullet \overrightarrow{P_0P}$$

leads to

$$P \in \mathscr{P} \Leftrightarrow \vec{\pi} \cdot \vec{p} = 0 \qquad (20)$$

Proof:

1. $$\vec{\sigma} \cdot \vec{p} = \left(\vec{e_o} + \vec{P} + \frac{1}{2}\left\|\vec{P}\right\|^2 \overrightarrow{e_\infty}\right) \cdot \frac{1}{\rho}\left(\vec{e_o} + \vec{\Omega} + \frac{1}{2}\left(\left\|\vec{\Omega}\right\|^2 - \rho^2\right)\overrightarrow{e_\infty}\right)$$
$$= \frac{1}{\rho}\left(\vec{P} \bullet \vec{\Omega} - \frac{1}{2}\left\|\vec{P}\right\|^2 - \frac{1}{2}\left(\left\|\vec{\Omega}\right\|^2 - \rho^2\right)\right)$$
$$= \frac{1}{2\rho}\left(-\left(\vec{P} - \vec{\Omega}\right)^2 + \rho^2\right)$$
$$= \frac{1}{2\rho}\left(-\vec{\Omega}P^2 + \rho^2\right) = -\frac{1}{2\rho}\chi_S(P)$$

Moreover,

$$P \in S \Leftrightarrow \vec{\sigma} \cdot \vec{p} = 0$$

2. $$\vec{p} \cdot \vec{\pi} = \left(\vec{e_o} + \vec{P} + \frac{1}{2}\left\|\vec{P}\right\|\overrightarrow{e_\infty}\right) \cdot \left(-\vec{N} - \left(-\vec{N} \bullet \overrightarrow{P_0}\right)\overrightarrow{e_\infty}\right) = \left(-\overrightarrow{P_0} \bullet \vec{N} + \vec{N} \bullet \overrightarrow{P_0}\right)$$
$$= -\vec{N} \bullet \overrightarrow{\mathscr{O}_nP} + \vec{N} \bullet \overrightarrow{\mathscr{O}_nP_0}$$
$$= -\vec{N} \bullet \left(\overrightarrow{\mathscr{O}_nP} + \overrightarrow{P_0\mathscr{O}_n}\right) = -\vec{N} \bullet \overrightarrow{P_0P}$$

Moreover, as $P \in \mathscr{P} \Leftrightarrow \vec{N} \perp \overrightarrow{P_0P}$, we obtain

$$P \in \mathscr{P} \Leftrightarrow \vec{\pi} \cdot \vec{p} = 0$$

The reader can note that the computation $\frac{-1}{2\rho}\left(\overrightarrow{\Omega P}^2 - \rho^2\right)$ in $\mathscr{E}_n$ is quadratic, whereas the linear computation $\vec{\sigma} \cdot \vec{p}$ in the Minkowski-Lorentz space gives the same result. The points of the paraboloid P which belong to a $n-1$-sphere are now characterized:

Corollary 1

Let S be a $n-1$-sphere of $\mathscr{E}_n$, of center Ω, of radius ρ and let $\vec{\sigma}$ be its representation in the Minkowski-Lorentz vector space.

Let $\mathscr{P}$ be a hyperplane of $\mathscr{E}_n$ passing through the point P_0, with a unit normal vector denoted by $\vec{N}$ and let $\vec{\pi}$ be its representation in the Minkowski-Lorentz vector space.

Let $\mathscr{H}_{\sigma^\perp}$ (resp. $\mathscr{H}_{\pi^\perp}$) be the hyperplane defined by O_{n+2} and its unit normal vector $\vec{\sigma}$ (resp.$\vec{\pi}$). Then

1. *The $n-1$-sphere S is the intersection between the paraboloid P and the hyperplane $\mathscr{H}_{\sigma^\perp}$.*
2. *The hyperplane $\mathscr{P}$ is the intersection between the paraboloid P and the hyperplane $\mathscr{H}_{\pi^\perp}$.*

Proof:

Let $\vec{p}$ be the light-like vector in the Minkowski-Lorentz vector space which represents the point P of $\mathscr{E}_n$.

From Formula (19), the point P belongs to the $n-1$-sphere S if and only if

$$\vec{\sigma} \cdot \vec{p} = 0$$

if and only if

$$\overrightarrow{O_{n+2}\sigma} \cdot \overrightarrow{O_{n+2}p} = 0$$

where p is the point of the paraboloid defined by

$$\overrightarrow{O_{n+2}p} = \vec{p}$$

The second property can be proved in the same way.

Relative Position of Two $n-1$-Spheres

Let i be an integer in {1,2}. Let $\overrightarrow{\sigma_i}$ be the representation on Λ^{n+1} of the $n-1$-sphere.

S_i of $\mathscr{E}_n$ of center Ω_i and of radius ρ_i. Then:

T

$$
\begin{aligned}
\overrightarrow{\sigma}\blacksquare\overrightarrow{\sigma_2} &= \frac{1}{\rho_1}\left(\overrightarrow{e_o} + \overrightarrow{\Omega_1} + \frac{1}{2}\left(\left\|\overrightarrow{\Omega}\right\|^2 - \rho_1^2\right)\overrightarrow{e_\infty}\right) \\
&\quad \times\blacksquare\frac{1}{\rho^2}\left(\overrightarrow{e_o} + \overrightarrow{\Omega_2} + \frac{1}{2}\left(\left\|\overrightarrow{\Omega_2}\right\|^2 - \rho_2^2\right)\overrightarrow{e_\infty}\right) \\
&= \frac{1}{\rho_1\rho_2}\left(\overrightarrow{\Omega_1}\bullet\overrightarrow{\Omega_2} - \frac{1}{2}\left(\left\|\overrightarrow{\Omega_1}\right\|^2 - \rho_1^2\right) - \frac{1}{2}\left(\left\|\overrightarrow{\Omega_2}\right\|^2 - \rho_2^2\right)\right) \\
&= \frac{1}{2\rho_1\rho_2}\left(-\left(\overrightarrow{\Omega_1} - \overrightarrow{\Omega_2}\right)^2 + \rho_1^2 + \rho_2^2\right) \\
&= \frac{1}{2\rho_1\rho_2}\left(-\left(\overrightarrow{\mathscr{O}_n\Omega_1} - \overrightarrow{\mathscr{O}_n\Omega_2}\right)^2 + \rho_1^2 + \rho_2^2\right) \\
&= \frac{1}{2\rho_1\rho_2}\left(-\overrightarrow{\Omega_2\Omega_1}^2 + \rho_1^2 + \rho_2^2\right) \\
&= \frac{1}{2\rho_1\rho_2}\left(-\overrightarrow{\Omega_2\Omega_1}^2 + \rho_1^2 + \rho_2^2\right)
\end{aligned}
$$

written as

$$
\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2} = -\frac{1}{2\rho_1\rho_2}\chi_{S_1,S_2} \tag{21}
$$

where $\chi_{S1,\,S2}$ is obtained from Formula (16). From Formula (21), some properties about the positions of two $n-1$-spheres can be deduced.

Proposition 4 *Relative position of two $n-1$-spheres of $\mathscr{E}_n$*

Let S_1 and S_2 be two $n-1$-spheres of $\mathscr{E}_n$ of centers Ω_1 and Ω_2, of respective radii ρ_1 and ρ_2 and let $\overrightarrow{\sigma_1}$ and $\overrightarrow{\sigma_2}$ be their representations on the space of spheres Λ^{n+1}. Then:

1. *The $n-1$-spheres S_1 and S_2 are secant if and only if $\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2}\right| < 1$.*
2. *The $n-1$-spheres S_1 and S_2 are orthogonal if and only if $\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2} = 0$.*
3. *The $n-1$-spheres S_1 and S_2 are tangent if and only if $\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2}\right| = 1$.*
4. *The $n-1$-spheres S_1 and S_2 are disjoint if and only if $\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2}\right| > 1$.*

Proof:
Using the reals $r_1 = |\rho_1|$ and $r_2 = |\rho_2|$, Formula (21) becomes

$$
\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2}\right| = \frac{1}{2r_1r_2}\left|\Omega_1\Omega_2^2 - r_1^2 - r_2^2\right| \tag{22}
$$

1. The $n-1$-spheres S_1 and S_2 are secant. Then

$$
\begin{aligned}
&|r_1 - r_2| < \Omega_1\Omega_2 < r_1 + r_2 \Leftrightarrow r_1^2 \\
&+r_2^2 - 2r_1r_2 < \Omega_1\Omega_2^2 < r_1^2 \\
&+r_2^2 + 2r_1r_2 \Leftrightarrow \left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2}\right| < 1
\end{aligned}
$$

2. The $n-1$-spheres S_1 and S_2 are orthogonal $\Leftrightarrow \chi_{S_1,S2} = 0 \Leftrightarrow \overrightarrow{\sigma}\blacksquare\overrightarrow{\sigma_2} = 0$.
3. The $n-1$-spheres S_1 and S_2 are external (resp. internal) tangent $\Leftrightarrow \Omega_1\Omega_2 = r_1 + r_2$ (resp. $\Omega_1\Omega_2 = |r_1 - r_2|$)$\Leftrightarrow \overrightarrow{\Omega_1\Omega_2}^2 = r_1^2 + r_2^2$

$$
\begin{aligned}
&+2r_1r_2 \quad \left(\text{resp.}\overrightarrow{\Omega_1\Omega_2}^2 = r_1^2 + r_2^2 - 2r_1r_2\right) \\
&\Leftrightarrow \left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2}\right| = 1
\end{aligned}
$$

.

4. The $n-1$-spheres S_1 and S_2 are disjoint, two cases are to be distinguished:

$$
\begin{aligned}
&\blacktriangleleft\Omega_1\Omega_2 > r_1 + r_2 \Leftrightarrow \Omega_1\Omega_2^2 > r_1^2 \\
&+r_2^2 + 2r_1r_2 \Leftrightarrow \left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2}\right| > 1
\end{aligned}
$$

$$
\begin{aligned}
&\blacktriangleleft\Omega_1\Omega_2 < |r_1 - r_2| \Leftrightarrow \Omega_1\Omega_2^2 < r_1^2 \\
&+r_2^2 - 2r_1r_2 \Leftrightarrow \left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\sigma_2}\right| > 1
\end{aligned}
$$

Let S_1 be a $n-1$-sphere of $\mathscr{E}_n$, of center Ω, of radius ρ and let $\overrightarrow{\sigma_1}$ be its representation on Λ^{n+1} in the Minkowski-Lorentz vector space. Let $\mathscr{P}_1$ be a hyperplane of $\mathscr{E}_n$ passing through the point P_1, of unit normal vector $-\vec{N}_1$ and let $\overrightarrow{\pi_1}$ be its $\mathscr{P}_1$ representation on Λ^{n+1} in the Minkowski-Lorentz vector space. Then:

$$\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}=\frac{1}{\rho_1}\left(\overrightarrow{e_o}+\overrightarrow{\mathscr{O}_n\Omega_1}+\frac{\left\|\overrightarrow{\mathscr{O}_n\Omega_1}\right\|-\rho_1^2}{2}\overrightarrow{e_\infty}\right)\blacksquare\left(-\overrightarrow{N_1}-\left(\overrightarrow{N_1}\bullet\overrightarrow{\mathscr{O}_nP_1}\right)\overrightarrow{e_\infty}\right)$$

$$=-\frac{1}{\rho_1}\left(\overrightarrow{\mathscr{O}_n\Omega_1}\bullet\overrightarrow{N_1}+\left(\overrightarrow{N_1}\bullet\overrightarrow{\mathscr{O}_nP_1}\right)\underbrace{\overrightarrow{e_o}\blacksquare\overrightarrow{e_\infty}}_{=-1}\right)=-\frac{1}{\rho_1}\left(\left(\overrightarrow{\mathscr{O}_n\Omega_1}-\overrightarrow{\mathscr{O}_nP_1}\right)\bullet\overrightarrow{N_1}\right)$$

and then

$$\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}=\frac{1}{\rho_1}\overrightarrow{\Omega_1P_1}\bullet\overrightarrow{N_1} \tag{23}$$

and an important result can be given:

Proposition 5 *Relative positions of a $n-1$-sphere and a hyperplane of $\mathscr{E}_n$.*

Let S_1 be a $n-1$-sphere of $\mathscr{E}_n$, of center Ω, of radius ρ and let $\overrightarrow{\sigma_1}$ be its representation on Λ^{n+1} in the Minkowski-Lorentz vector space.

Let $\mathscr{P}_1$ be a hyperplane of $\mathscr{E}_n$ passing through the point P_1, of unit normal vector $-\vec{N}_1$ and let $\overrightarrow{\pi_1}$ be its representation on Λ^{n+1} in the Minkowski-Lorentz vector space.

Then:

1. *The $n-1$-sphere S_1 and the hyperplane $\mathscr{P}_1$ are secant if and only if*

$$\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}\right|<1$$

2. *The $n-1$-sphere S_1 and the hyperplane $\mathscr{P}_1$ are orthogonal if and only if*

$$\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}=0$$

3. *The $n-1$-sphere S_1 and the hyperplane $\mathscr{P}_1$ are tangent if and only if*

$$\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}\right|=1$$

4. *The $n-1$-sphere S_1 and the hyperplane $\mathscr{P}_1$ are disjoint if and only if*

$$\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}\right|>1$$

Proof:

Let P_1 be the orthogonal projection of the point Ω_1 onto the hyperplane $\mathscr{P}_1$ and Formula (23) becomes

$$\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}\right|=\frac{P_1\Omega_1}{|\rho_1|} \tag{24}$$

1. The $n-1$-sphere S_1 and the hyperplane $\mathscr{P}_1$ are secant $\Leftrightarrow P_1\Omega_1<|\rho_1|\Leftrightarrow\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}\right|<1$.
2. The $n-1$-sphere S_1 and the hyperplane $\mathscr{P}_1$ are orthogonal $\Leftrightarrow\Omega_1=P_1\Leftrightarrow\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}=0$.
3. The $n-1$-sphere S_1 and the hyperplane $\mathscr{P}_1$ are tangent $\Leftrightarrow P_1\Omega_1=|\rho_1|\Leftrightarrow\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}\right|=1$.
4. The $n-1$-sphere S_1 and the hyperplane $\mathscr{P}_1$ are disjoint $\Leftrightarrow P_1\Omega_1>|\rho_1|\Leftrightarrow\left|\overrightarrow{\sigma_1}\blacksquare\overrightarrow{\pi_1}\right|>1$.

Let i be an integer in $\{1,2\}$. Let $\mathscr{P}_1$ be a hyperplane of $\mathscr{E}_n$ passing through the point P_i, of unit normal vector $-\vec{N}_i$ and let $\overrightarrow{\pi_i}$ be its representation on Λ^{n+1} in the Minkowski-Lorentz vector space. Then

$$\overrightarrow{\pi_1}\blacksquare\overrightarrow{\pi_2} = \left(-\overrightarrow{N_1} - \left(\overrightarrow{N_1}\bullet\overrightarrow{\mathscr{O}_n P_1}\right)\overrightarrow{e_\infty}\right) \blacksquare\left(-\overrightarrow{N_2} - \left(\overrightarrow{N_2}\bullet\overrightarrow{\mathscr{O}_n P_2}\right)\overrightarrow{e_\infty}\right) = \overrightarrow{N_1}\bullet\overrightarrow{N_2} \tag{25}$$

and an important result can be given:

Proposition 6 *Relative positions of two hyperplanes of* $\mathscr{E}_n$

Let i be an integer in {1,2}. *Let* $\mathscr{P}_1$ *be a hyperplane of* $\mathscr{E}_n$ *passing through the point* P_i, *of unit normal vector* $\overrightarrow{N_i}$ *and let* $\overrightarrow{\pi_i}$ *be its representation on* Λ^{n+1} *in the Minkowski-Lorentz vector space.*

Then

1. *The hyperplanes* $\mathscr{P}_1$ *and* $\mathscr{P}_2$ *are orthogonal if and only if* $\overrightarrow{\pi_1}\blacksquare\overrightarrow{\pi_2} = 0$.
2. *The hyperplanes* $\mathscr{P}_2$ *and* $\mathscr{P}_2$ *are parallel if and only if* $\left|\overrightarrow{\pi_1}\blacksquare\overrightarrow{\pi_2}\right| = 1$.
3. *The hyperplanes* P_1 *and* P_2 *are secant if and only if* $\left|\overrightarrow{\pi_1}\blacksquare\overrightarrow{\pi_2}\right| < 1$.

Proof: From Formula (25).

As a point is a degenerate sphere, i.e., the radius is 0, one can remark:

Remark 2

Let Ω *a point of* $\mathscr{E}_3$ *and* $S(\rho)$ *a family of* $n-1$*-spheres of centers* Ω *and of radii* ρ.

The representations of $S(\rho)$ *on* Λ^{n+1} *are* $\vec{\sigma}(\rho)$. *Formulas* (9) *and* (12) *lead to*

$$\lim_{\rho\to 0}\rho\vec{\sigma}(\rho) = \left(\overrightarrow{e_0} + \vec{\Omega} + \frac{1}{2}\left\|\vec{\Omega}\right\|^2\overrightarrow{e_\infty}\right) = \vec{\omega}$$

and then, the limit of the vectors $\vec{\sigma}(\rho)$ *is the vector* $\vec{\omega}$ *which represents the center of the* $n-1$*-spheres.*

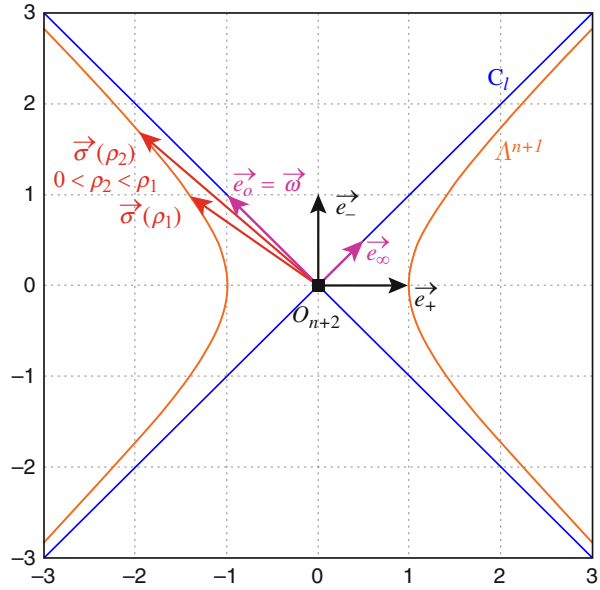
Figure 6 shows an example with

$$\Omega = \mathscr{O}_n$$

and

$$\vec{\sigma}(\rho) = \frac{1}{\rho}\overrightarrow{e_o} - \frac{\rho}{2}\overrightarrow{e_\infty}$$

and in the 2-plane defined by O_{n+2} and the light-like vectors $\overrightarrow{e_o}$ and $\overrightarrow{e_\infty}$, the representations of the $n-1$-spheres belong to a unit circle of center O_{n+2}. The equation of this circle in the reference frame $\left(O_{n+2}, \overrightarrow{e_o}, \overrightarrow{e_\infty}\right)$ is $x_o\, x_\infty = 1$,



Theory of Minkowski-Lorentz Spaces, Fig. 6 When the radii ρ of the $n-1$-spheres $S(\rho)$ of center Ω tend to 0, the representations $\vec{\sigma}(\rho)$ of $S(\rho)$ belong to an unit circle and tend to the light-like vector $\vec{\omega}$ representing the point Ω. The two lines which define the light-cone C_l are the asymptotes of the unit circle which looks like a rectangular hyperbola

whereas its equation in $(O_{n+2}, \overrightarrow{e_+}, \overrightarrow{e_-})$ is $x_+^2 - x_-^2 = 1$.

Envelope of $n-1$-Spheres

In this section, a one-parameter family $\mathscr{F}$ of oriented $n-1$-spheres S(t) of $\mathscr{E}_2$ or $\mathscr{E}_3$ is considered. If the envelope exists, each sphere of this family is tangent to the envelope S along a characteristic $n-2$-sphere. If $n=3$, a canal surface is obtained among others like quadrics of revolution or Dupin cyclides. Some conditions to obtain a canal surface are given in Langevin and Solanes (2011).

Naturally, the representation of $\mathscr{F}$ in the Minkowski-Lorentz space is a curve $t \mapsto \sigma(t)$ on $\Lambda^{n+1} \cup \mathscr{I}$ where $\mathscr{F}$ is $\varnothing$ or a set of light-like vectors which represents the degenerate $n-1$-spheres of the family or the point at the infinity of $\mathscr{E}_n$. A characteristic $n-2$-sphere is the intersection between two $n-1$-spheres: one is belonging to $\mathscr{F}$ and the other must be computed. To do that, the notion of derivative sphere is introduced.

Definition 8 *Derivative sphere*

Let $t \mapsto \sigma(t)$ be a curve, defined on the interval I, on Λ^{n+1} in the Minkowski-Lorentz space representing a one-parameter family $\mathscr{F}$ of oriented $n-1$-spheres $S(t)$ of $\mathscr{E}_n$ such that

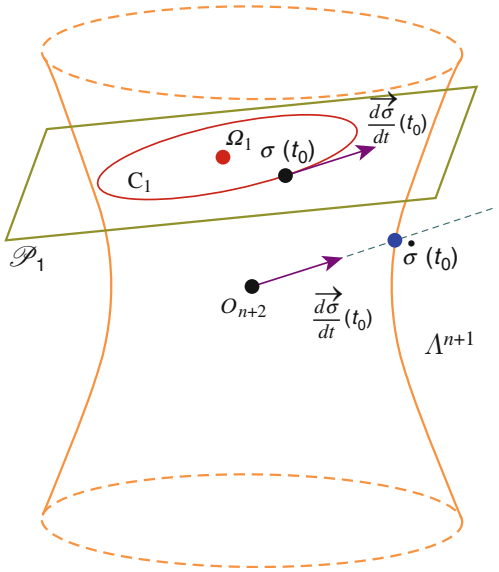
$$\forall t \in I, \quad \left(\overrightarrow{\frac{d\sigma}{dt}}(t)\right)^2 > 0$$

The derivative sphere of the sphere $\sigma(t_0)$ is the sphere $\dot{\sigma}(t_0)$ defined by

$$\left\{\dot{\sigma}(t_0)\right\} = \left[O_{n+2}, \overrightarrow{\frac{d\sigma}{dt}}(t_0)\right) \cap \Lambda^{n+1} \qquad (26)$$

The derivative sphere of the sphere $S(t_0)$ is the sphere $\dot{S}(t_0)$ defined by $\dot{\sigma}(t_0)$ (Fig. 7).

The characteristic $n-2$-sphere is the intersection between the $n-1$-sphere S (t_0) and the $n-1$-sphere $\dot{S}(t_0)$. Moreover, these two spheres S(t_0) and $\dot{S}(t_0)$ are orthogonal: from the relation



Theory of Minkowski-Lorentz Spaces, Fig. 7 On Λ^{n+1}, construction of a characteristic $n-2$-sphere when the curve C_1 defined by the one-parameter family F is a circle

$$\forall t_0 \in I, \quad \overrightarrow{O_{n+2}\sigma(t_0)}^2 = 1$$

and after derivation, the following formula is obtained

$$\overrightarrow{O_{n+2}\sigma(t_0)} \cdot \overrightarrow{O_{n+2}\dot{\sigma}(t_0)} = 0.$$

Moreover, if the spheres $\sigma(t)$ define a circle C_1 on Λ^{n+1}, the center Ω_1 of C_1 is the orthogonal projection of the center O_{n+2} of the unit sphere Λ^{n+1} onto the 2-plane $\mathscr{P}_1$ defined by C_1 (Fig. 7).

A Dupin cyclide is a canal surface in $\mathscr{E}_3$ in two equivalent ways. Figure 8 shows a characteristic circle on a horned Dupin cyclide obtained as intersection of two perpendicular 2-spheres $S(t_0)$ and $\dot{S}(t_0)$. The centers of the 2-spheres belong to an ellipse or to a hyperbola.

Figure 9 shows an other canal surface. The center of the spheres belong to the curve

$$\gamma_0(u_0) = (8\cos((u_0)); 8\sin(u_0), u_0)$$

with $u_0 \in \left[-7\frac{\pi}{2}; 9\frac{\pi}{2}\right]$ and the radii of these spheres are $R(u_0) = \cos^2(u_0) + \frac{1}{4}$.

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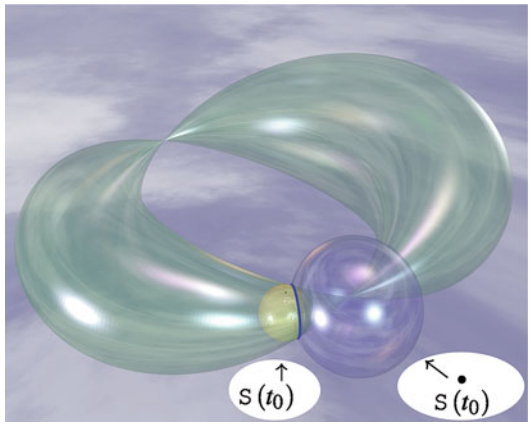

Theory of Minkowski-Lorentz Spaces, Fig. 8 Construction, in E_3, of a characteristic circle on a horned Dupin cyclide using a Minkowski-Lorentz space (Fig. 7)

Theory of Minkowski-Lorentz Spaces, Fig. 9 Example of a canal surface

Conclusion

This entry presents a survey on the Minkowski-Lorentz space and its interest for Computer Graphics. In a future entry, the representation of spheres in the Minkowski-Lorentz space is applied to solve classical geometric problems like Apollonius problems or some Dupin problems and the determination of an envelope of a family of oriented circles or spheres.

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Third-Person

► Fortnite: A Brief History

Three Dimensional

► Sketch-Based Posing for 3D Animation

Three/Two Dimensional (3D/2D) Graphics

▶ Imagineering Ceramic Pottery Using Computer Graphics

Three-Dimensional Picture

▶ Holography, History of

Timed Automata for Video Games and Interaction

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Synonyms

Formal methods; Interactive multimedia scenarios; Player experience; Serious games

Definition

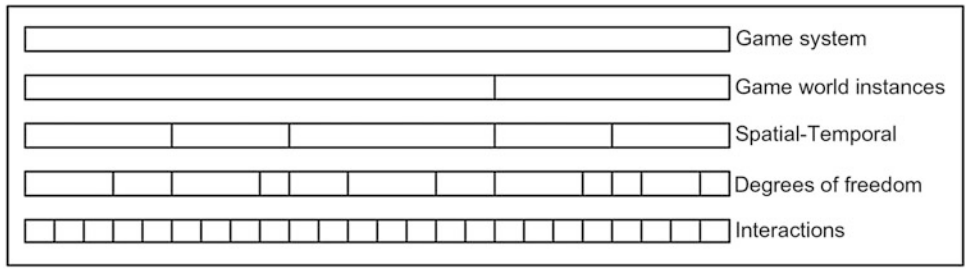
Timed Automata is a formalism for modelling and verification of time-critical systems. It has been proven to be a formalism that is well adapted to the expression of the timing constraints appearing in interactive scores and video games, because it is a powerful model for describing both the logical ordering of the events in such scenario and also the duration of events and the timing between them.

Introduction

As coined by Espen Aarseth in his very first editorial launching the "game studies" journal (considered as one of the core events establishing "game studies" as an academic field), games are "*both object and process [which] must be played. Playing is integral, not coincidental [. . .]. The complex nature of simulations is such that a result cannot be predicted beforehand; it can vary greatly depending on the players luck, skill and creativity.*" (Aarseth 2001). Activating a video game requires a processing of player(s) inputs, directly impacting the game system evolution, both **temporally** (unfolding the game narrative and ludic progression) and **conditionally** (tailoring the game accordingly to the player behavior and the gameplay elements reactions).

Segmenting play Since early ("*vintage*") arcade games, temporal and conditional (i.e., challenge) segmentation of gameplay have been considered as core perspectives to simultaneously design and analyze video games (Zagal et al. 2008). In games, time is employed as a resource (divisions, temporal limit, etc.) and/or a coordination mechanism (rounds, turn-taking, narrative key moments, etc.) (Zagal et al. 2008, p. 180). Challenges, on their sides, condition the way player(s) can interact with a game system (a change in challenge is, in general, accompanied by a change of allowed activations). Another segmentation identified by Zagal et al. is the *spatial* one, which is the "*division of the gameworld into different spaces that also partition the gameplay*" (Zagal et al. 2008, p. 182). The spatial segmentation is tied to the creative process of level designing, itself tied to the notion of **hierarchy**. Indeed, a *level* can be seen as a spatial segment containing specific *gameplay elements*, themselves interactable regarding the current *degree of freedom* enabled to the player. It is noteworthy that other game studies research, such as the six dimensions of implication identified by Gordon Calleja (2011), also regularly encompass time (narration, emotion), condition (ludic, kinesthesic, social), and space/hierarchy (strategy).

Hierarchy in games Segmenting a video game hierarchically has also been suggested by Raphaël Marczak as part of the *Gameplay Performance Segmentation model* (Marczak 2014, chapter 4), which defines five hierarchical layers of



Timed Automata for Video Games and Interaction, Fig. 1 The five hierarchical layers of the Gameplay Performance Segmentation model. (Marczak 2014, chapter 4)

analysis, toward the understanding of how a specific player actually engaged with a specific game system, contextualizing each interaction from within the whole game system: the game system layer represents to top level, then including different game instances, themselves separated in different time and space segments, containing different phases conditioning the level of freedom offered to a player at a given time, to the bottom level being the actual interaction performed by the player (see Fig. 1).

Gameplay elements themselves are hierarchically related, as emphasized by the *Game Ontology Project* (Zagal et al. 2005), classifying gameplay concepts by affiliations and groups of dependencies. For example, a *head up display* in a first person shooter game is part of *visual output*, itself part of *sensory output*, part of *presentation*, and finally part of the top theme *interface*.

Example An example illustrating the three segmentation axis emphasized above (time, condition, and hierarchy) can be seen on Fig. 2, displaying a boss fight in the game *The Legend of Zelda: The Windwaker HD* (Nintendo 2013). In terms of *hierarchy*, this boss fight happens in an enclosed arena, in which the player's avatar (Link) can find specific items in relation with the fight (mostly life-regenerating items), and the actual boss (itself subdivided into three main components: two hands and a head). *Time-wise*, the boss behavior follows a pattern during which it opens and closes its hands, mouth, and eyes, and moves within the arena. This pattern has to be learned by the player in order to correctly defeat the boss (shooting its eyes and mouth). In terms of *conditions*, the player must switch between weapons (arrow, bomb, etc.) in order to react accordingly to the boss current pattern. Each weapon has its own control and impacts the game space differently. This simple example illustrates how these three axis work concurrently.

Another example of time, condition, and hierarchy segmentation can be read in Marlène Dulaurans and Raphaël Marczak paper about the game *Clash Royal* (Dulaurans and Marczak 2018).

Game engines, such as *Unreal Engine*, *Unity3D*, *Godot*, *Game Make Studio* (to name a few), are now widely available to game designers, developers, and the general public, for supporting game making whether in companies or for independent creatives. Time, condition, and hierarchy are all encompassed in these engines, but as separated elements, and rarely displayed all-together in the same interface and representation. In *Unity3D,* for example, hierarchy is linked with graphical entities (a gameobject can be a child of another gameobject); condition is part of the C#/javascript scripting feature, or for animators; and time is managed by the game engine scheduler (calling update functions each frame) or by the scripting ability to change level/scene. Other engines, like *Unreal Engine*, *Godot* or *Game Make Studio* also have a blue-print feature, making visual the conditional possibilities.

These three main features constituting a gameplay are included in all game engines software, **but they are not part of a general scenario/representation structure, able to, at the same time, model time, condition, and**

Timed Automata for Video Games and Interaction, Fig. 2 A boss in Zelda The Windwaker HD (Nintendo 2013), illustrating the three main segmentation axis: time, condition, and hierarchy

hierarchy. For that reason, during the last few years, a promising interactive score system called *i-score* (https://ossia.io/) has been emerging with the main objective of blending together the above three features for performing art and video games. This software can be seen as a (1) *conductor* (in the musical sense), scheduling media with the flexible time concept, and as a (2) *Master Hand* (in the role playing sense), structuring a game design both temporally, conditionally, and hierarchically.

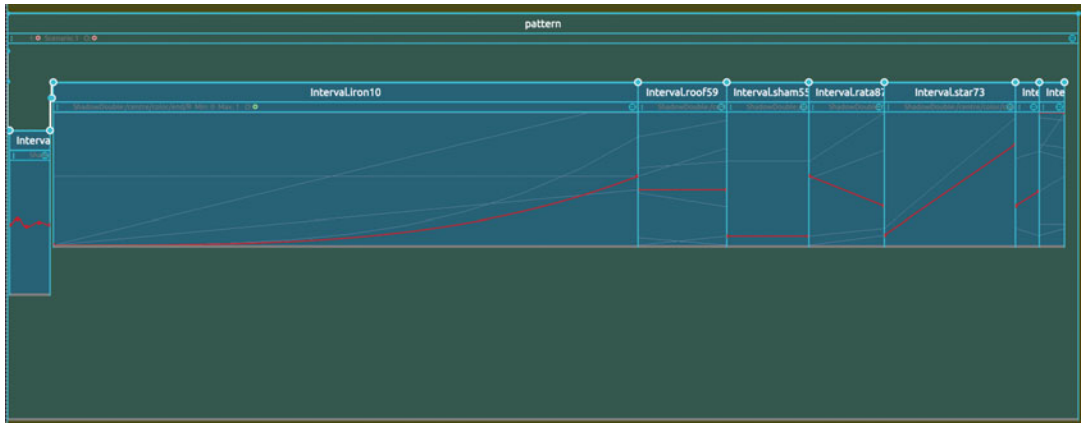
Interactive Scores with i-score

i-score provides a theoretical framework and a graphical application for the authoring and execution of interactive scores. Interactive scores consist of a temporal and hierarchical organization of events that allow users to describe interactions of the performer during the performance of the score. These interactions allow the possibility for a score to have more than one different possible performances.

The graphical model for i-score was introduced by Celerier et al. 2015. This model is based on hierarchy of graphical elements whose semantics allows to describe the flow of time. Moreover, it is adapted for the authoring of automation and processes which are happening over a duration of time, either fixed or dependent on interactive events (see Fig. 3). i-score is closer in mind to sequencers like Reaper®, Ableton Live®, or Avid Pro Tools®, than music notation software such as Finale®, Sibelius® or Bach®. For instance, Fig. 3 shows an i-score score controlling over time the brightness, the intensity, and the colors of a light projected on a surface in order to play with the spectators' perception of time and lead them to a more thoughtful mental state.

In general, interactive scores are described by powerful expressive models similar to full-fledged programming languages, e.g., the programming language for real-time and interactive computer music *Chuck* (Wang et al. 2015). The above has the main consequence of putting the users in front of the common problems that occur during the activity of programming, leading to undesired behaviors during the performance: bugs, data races, and specification problems. Hence, the need for advance verification techniques for interactive score software becomes necessary.

Multiple families of formal methods, such as Petri nets (Desainte-Catherine et al. 2013; Arias et al. 2014), process calculi (Toro et al. 2014; Olarte and Rueda 2009), and linear logic (Arias et al. 2015a), have been proposed to give formal semantics to i-score, with the goal of performing static verification on the score in order to prevent unwanted situations during the performance. However, the proposed models do not support (1) flexible control structures such as *conditionals* and (2) practical mechanisms for the *automatic verification* of scores.



Timed Automata for Video Games and Interaction, Fig. 3 Interactive score controlling over time a light projected on a surface in order to play with the spectators' perception of time and lead them to a more thoughtful mental state. Score created by The Baltazars (http://www.baltazars.org/)

In 2015, a novel model of i-score using Timed Automata was defined (Arias et al. 2015b). This model expresses, in the same framework, the main features of interactive scores (i.e., time, conditions and hierarchy). Moreover, it allows to verify the written scores automatically. Timed Automata has been proven to be a formalism that is well adapted to the expression of the timing constraints appearing in an interactive score following system (Sanchez and Jacquemard 2016; Echeveste et al. 2013; Jacquemard and Poncelet 2016), because it is a powerful model for describing both the logical ordering of the events in such scenario and also the duration of events and the timing between them.

In the next, a formal definition of Timed Automata model is presented and also some important properties of interactive scores that can now be proven.

Formal Verification of Interactive Scores in i-score

Timed Automata (Alur and Dill 1994) is a formalism for modelling and verification of time-critical systems. A timed automaton (see Fig. 4) is a finite-state machine with a finite set of real-valued variables modelling logical *clocks*. A *transition* in a timed automaton (represented by an edge) is labelled with a *guard* (i.e., when is it allowed to take an edge?), an *action* (i.e., what is performed when taking the edge), and a set of clocks (i.e., which clocks must be reset). A *location* (represented by a node) is equipped with an *invariant* that constrains the amount of time that may be spent in that location. In that sense, invariants ensure the progress of the model while guards restrict the behavior of the timed automaton. Both invariants and guards are *clock constraints* that are formally defined in Definition 1.

Definition 1 A *clock constraint* δ over a set C of clocks is defined inductively by

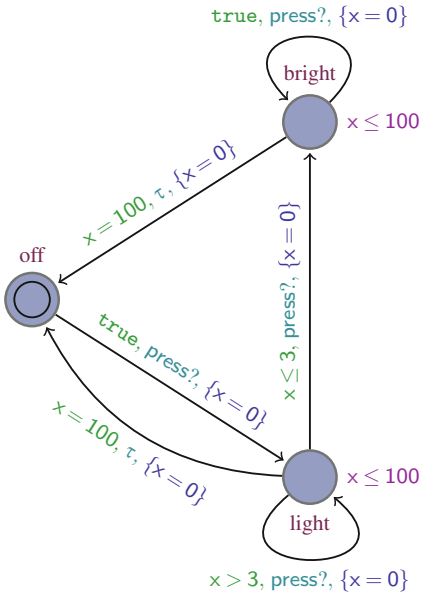
$$\delta ::= x \sim n \mid \delta_1 \wedge \delta_2 \mid \text{true}$$

where $n \in \mathbb{N}_0, \sim \in \{=, <, >, \leq, \geq\}$, and $x \in C$. Let $\Phi(C)$ denote the set of clock constraints over C, and $\Phi_<(C)$ the set of *downward closed* clock constraints of the form $x \leq n$ and $x < n$.

The formal definition of a timed automaton is as follows.

Definition 2 A *timed automaton* is a tuple $\langle L, l_0, \Sigma, C, E, I \rangle$, where

- L is a finite set of *locations*.
- $l_0 \in L$ is the *initial* location.



Timed Automata for Video Games and Interaction, Fig. 4 A light switch modelled as a timed automaton. (Fahrenberg et al. 2010)

- Σ is a finite alphabet denoting *actions*.
- C is a finite set of *clocks*.
- $E \subseteq L \times \Phi(C) \times \Sigma \times 2^C \times L$ is the set of transitions between locations.
- $I: L \to \Phi < (C)$ assigns invariants to locations.

Figure 4 shows the timed automaton model of the intelligent light switch defined in (Fahrenberg et al. 2010). The initial state of the model is off that listens for the pressing of the button in order to turn the light on (i.e., state light). Once the light is on, it waits for 100 time units (i.e., until clock $x = 100$). If an additional press is done during this time, the clock x is reset and prolongs the time in the state by 100 time units, otherwise the light turns off again. Pressing the button twice, with at most three time units between the presses, triggers a special bright light.

The Timed Automata model for i-score scores was formalized in (Arias et al. 2017, 2015b). Currently, i-score is equipped with an automatic tool for translating scores into their equivalent Timed Automata model. It covers a strict subset of i-score because the latter is based on a plug-in architecture which is easily extensible. For instance, a plug-in allowing to run arbitrary Javascript code.

The verification of scores is carried out using the UPPAAL (David et al. 2015) model-checker, which allows for the verification of networks of Timed Automata using the method of model-checking (Clarke et al. 2018). Roughly speaking, model-checking is a computer-assisted method for the analysis of systems that explores exhaustively all possible system states in a systematic manner in order to check whether a model of the system satisfies a given property.

Once the Timed Automata model of the score is generated by i-score, it is possible to check the following useful properties with UPPAAL:

- The temporal exclusivity of two multimedia processes P_1 and P_2. That means that in all possible executions of a score, always both P_1 and P_2 are not executed at the same time. This is important, for instance, if a multimedia device can only handle one automation at the same time.
- The unreachability of an *error* state. That is, in all possible executions of the score, all the multimedia processes never reach an error state (i.e., all the temporal constraints of the system are always satisfied).
- It is possible to assert that given an annotation of the multimedia processes relative to the part they pertain to (e.g., Intro, Chorus, Verse), the score's structure satisfies a specific order. For instance, the Intro is always followed by a Chorus.

Applications to Games and Interaction

In the following, two special applications of i-score in the domain of games and interaction are presented.

SEGMent

SEGMent (*Study and Education Game Maker and entertainment*) is a diagram-based game making language allowing anyone willing to create (digital) escape games to compose multimedia scenarios without any programming skill

pre-required. From the three main phases of game-making process, being conception (brainstorming, story-boarding, proof of concept, etc.), implementation (technical programming of the game) and experience (gameplay metrics gathering (Drachen and Canossa 2009; Marczak et al. 2015) for analysis and understanding); SEGMent is handling the two intimidating ones from non-computer scientist perspective (implementation and experience), so that anyone, from professors, students to game designer, can fully focus on the conception phase. The main objective of SEGMent is to help teachers create ludo-pedagogical experiences in relation to their discipline, in the form of an escape game (including still images, sounds, animations, videos, digicode/keypad behavior for user input, object states, etc.), by the simple drawing of a diagram. The main features of SEGMent are:

- Scenes background creation.
- Objects addition in scenes (hierarchically).
- Click areas to go from one scene to another (hierarchically).
- Background atmospheric sound for scenes.
- Possibility to interact with objects and change their states (condition).
- Object animation when changing state (time).
- Self-reflexive dialog the first time a user enters a scene (time).
- Possibility to interact with areas on screen to generate input (like digicode or keyboard) (condition).
- Possibility to move elements as puzzle pieces (condition).
- Possibility to go from one scene to another by entering an answer (manually or with generated input) or by having several objects in specific states (condition).
- Possibility to go directly to another scene after a specified amount of time (time).
- Possibility to go back to the previous scene (time), etc.

From SEGMent to SEGMent^2

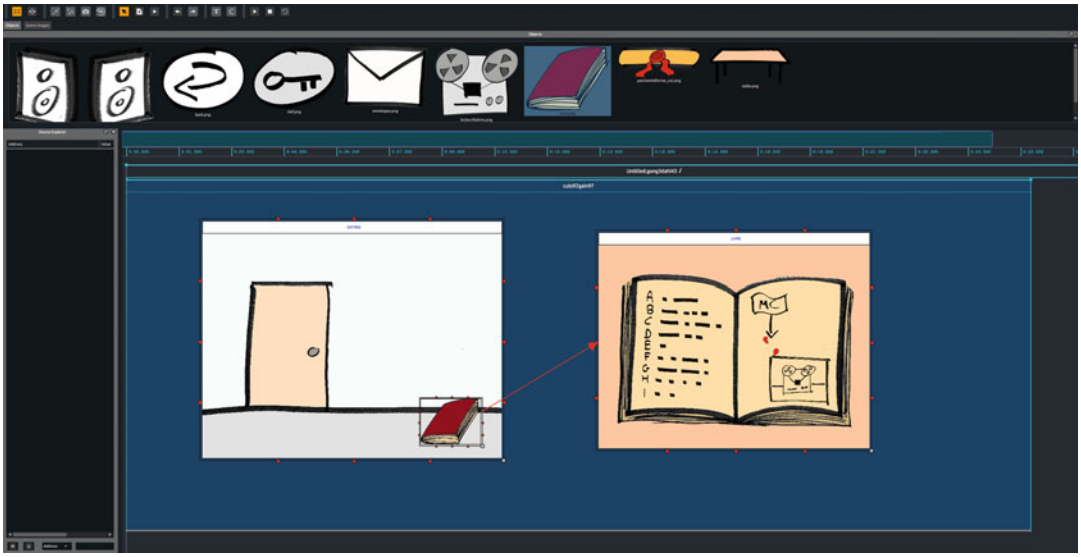
SEGMent was originally designed as a proof of concept. The SEGMent-engine is implemented in Unity3D and can be launched on MacOSX, Windows, Linux, Android, and online (WebGL). The diagram editor is, for its part, based on *DIA Diagram Editor* (http://dia-installer.de/), where flow chart has been adapted for escape game-making properties. DIA is a perfect diagram drawing tool; however, it lacks the ability to easily add custom properties on state/transition objects, and hierarchy is not implemented for including an image (object) into another (scene). Editing a SEGMent scenario in DIA can be really cumbersome for a neophyte. Therefore, for a proof of concept, DIA has perfectly fulfilled its job, but the need to have a fine management of time, condition, and hierarchy forced to switch to another editor environment: i-score. This new engine is the main goal of SEGMent^2.

By using the plug-in management system included in i-score, it becomes possible to port all the above mention features of SEGMent within the i-score environment, thus taking advantage of the time, condition, and hierarchy possibilities offered by the system. As illustrated in Fig. 5, objects in scenes are now fully enclosed into them (hierarchically) and each element (scenes, objects, transitions, etc.) can have time and condition tied to it, as custom property. Furthermore, SEGMent being now in i-score means that it can be linked with other i-score plug-ins, and notably the ones about flexible time (useful in game scenario, where the player inputs condition the narrative unfolding) and about parameters automation. Finally, a SEGMent scenario can now be separated into several sublevel, easing the game and level designers tasks.

With SEGMent^2, it is now possible to say that i-score is not only a multimedia **conductor** but also a **master hand**, able to guide the scenarization of video games.

VMO-Score

Machine improvisation refers to artificially augmented musical performances where machines contribute creatively to the musical outcome. Musicians use machine analysis tools to generate a computer accompaniment from musical examples. This allows the computer to generate music in ways that preserve the style of the musical examples given to it without a need for



Timed Automata for Video Games and Interaction, Fig. 5 Screen capture displaying the SEGMent^2 plugin within i-score

programming. During performance, these generative mechanisms are either controlled in real-time by another operator or are programmed to interact according to readily prepared scenarios.

Variable Markov Oracle (VMO) (Wang and Dubnov 2015) is a machine improvisation method based on automatic analysis of the musical structure of a recording. A VMO is a data structure capable of identifying repeated subsequences within a multivariate time series. After symbolizing the time series, repetitive structures can be extracted and used for music improvisation.

Currently, interactive music pieces require separate phases of constructing generative models and structuring them into a larger compositional plan. In Arias et al. (2016), a new system is proposed in which the machine improvisation tools based on VMO is combined with i-score scores in order to control the improvisation according to larger structures found directly from a musical recording and real-time interactions defined by the user. This allows construction of improvisation scenarios in ways that (1) are organic with the musical materials used for generating the music and (2) interact with the performer/environment during the improvisation.

Conclusion

We showed that the interactive score system *i-score* is able to specify scenarios featuring time, conditions, and hierarchy, which are essentials for exhaustive interactive systems such as performing art and video-games. Moreover, we presented a formal model for i-score, showing that Timed Automata is a well-suited formalism for the modelling and verification of interactive systems where both logical and temporal constraints are needed for a rigorous interactive creation.

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Tools

▶ Virtual Reality Game Engines

Touch

▶ Tactile Visualization and 3D Printing for Education

Toxic Behavior

▶ Player Abusive Behavior Detection
▶ Toxic Behaviors in Online Gaming

Toxic Behaviors in Online Gaming

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Synonyms

Gray zone; Toxic behavior; Unsportsmanlike behavior

Definitions

Toxic behavior refers to actions that have a detrimental impact on other players in online games. Gray zone users exhibit behavior that falls between toxic and normal users. While technically permissible, unsportsmanlike behavior is a form of conduct that can negatively affect other players.

Introduction

Online gaming has become a popular leisure activity for individuals seeking refreshment and enjoyment. However, several factors within the virtual gaming world can impede this experience, including toxic behavior. The anonymity of cyberspace often makes it easier for individuals to engage in immoral actions compared to real-life interactions (Davenport 2002; Suler 2004). This type of behavior not only diminishes the satisfaction of other players but also harms the reputation of the game. As a result, game developers have implemented various measures to prevent toxic behavior. However, there is no universally accepted definition of toxic behavior (Canossa et al. 2021) and no definitive solution to addressing it (Adinolf and Turkay 2018). This entry aims to investigate toxic behavior by broadly defining it as any actions that cause psychological harm to other players or damage resources within online games.

Toxic behavior can be divided into two main categories based on the methods used to execute it: (1) *Outside of games*, utilizing tools or programming that exist outside the game world, and (2) *Inside of games*, utilizing only the functions available within the game world. Examples and key characteristics of each type of behavior are outlined in Table 1.

Initially, *Outside of games* alters the intended gameplay of the developers, thereby undermining the fairness of the game and ultimately damaging the game world (Han et al. 2022). Such actions are widely regarded as negative within the context of online games. These include the utilization of game bots to acquire an unfair advantage or using illegal programs to secure victories. Additionally, this category encompasses the modification or duplication of programs to establish private servers or to exploit hacking vulnerabilities. The primary motivation for these actions is often financial gain in the real world, and cheating is utilized to achieve success within the game.

On the other hand, some behaviors are not problematic from a mechanical perspective but problematic from a user's perspective. These actions, referred to as *Inside of games*, follow

Toxic Behaviors in Online Gaming, Table 1 Category of all toxic behaviors in online games

Division	Subdivision	Goal	Example
Outside of games	Using external tools	Money, win	Game bot, wall hack, aim bot . . .
	Modding	Money	Private server, server hacking . . .
Inside of games	Trolling, griefing	Fun, hate	Aiding the enemy, spamming . . .
	Unsportsmanlike behavior	Win	Cheap play, road block . . .

the rules set by the game world, but they offend other users and adversely affect the game world, such as causing players to leave. This is because online games are also a type of society. Trolling and griefing (Achterbosch et al. 2017) are prime examples and include intentionally losing and speaking rudely, etc.

Trollers or griefers, troublemakers, irritate other players only for their own amusement. The main reasons for trolling are psychological factors such as boredom, attention-seeking, and revenge (Shachaf and Hara 2010). Other similar behaviors include unsportsmanlike behavior, which is motivated by a desire to win and achieve more in battles. Detailed actions of unsportsmanlike behavior are described in Table 2.

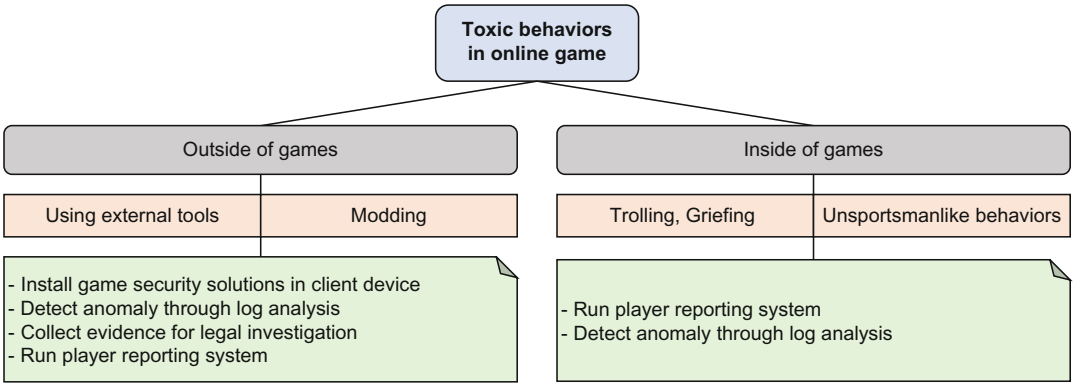
Toxic Behaviors in Online Gaming, Table 2 Unsportsmanlike behaviors

Behavior type	Description
Break teamwork	Seeking only their own benefits
Roadlock	Hindering other players from moving forward
Offensive chatting	Blaming others, speaking sarcastically
Deliberate defeat	Intentionally losing games to profit a particular user's account
Cheap play	Repeating a certain play pattern for win
Overkill	Immoderately killing other players
Unintended use	Using the in-game environment to block other players' viewing, clicking, etc.
Using NPC	Dragging the monsters to damage other players

There are several approaches that can be taken to address malicious actions. One method of countering *Outside of games* is to install security solutions on client devices. These software programs monitor the device and block any abnormal behavior detected. However, it is important to verify that the security solution has not been tampered with, and there is a significant drawback that additional software installations can negatively impact the user experience.

As a result, this method of installing additional software on client devices is not widely used in practice (Woo and Kim 2012). Another approach is to utilize information generated within the game. This includes analyzing logs to identify and block users who are behaving abnormally. For instance, if a game bot is being used, it will exhibit regular patterns of behavior. Since the logs are collected from the server and analyzed, this method does not affect gameplay or cause inconvenience to users. Log analysis techniques can range from simple rule-based methods to more advanced techniques using machine learning or deep learning. Another countermeasure is to collect legal evidence and respond through legal means. Lastly, there is the option of implementing a reporting system for users (Kwak et al. 2015).

Since *Inside of games* involves human manipulation, the mechanical aspect is not a concern. Therefore, the only countermeasures available rely on reporting and analyzing data generated within the game. While detecting *Inside of games* is more challenging than *Outside of games*, it is possible to analyze patterns of problematic behavior in order to detect and prevent it in advance. However, defining the specific problematic behavior is a significant challenge. This is why gray zone users often exist, as it can be difficult to accurately identify and control toxic behavior within the game. Above all, when many users get penalties for toxic behavior, it can make users feel that their freedom is restricted and cause dissatisfaction, leading to negative consequences


Toxic behaviors in online game
Outside of games
Inside of games
Using external tools
Modding
Trolling, Griefing
Unsportsmanlike behaviors
- Install game security solutions in client device
- Detect anomaly through log analysis
- Collect evidence for legal investigation
- Run player reporting system
- Run player reporting system
- Detect anomaly through log analysis

Toxic Behaviors in Online Gaming, Fig. 1 Overview of toxic behaviors in online games and countermeasures

such as user abandonment. Figure 1 illustrates the actions and countermeasures described above. This entry introduces methods for detecting and preventing various toxic actions in online games through data analysis.

Related Works

This section examines the motivations and characteristics of toxic users within the field of online game security. Furthermore, it explores studies on methods for detecting and preventing toxic behavior in these communities.

Consalvo (2009) provided an overview of the history of cheating within video games and highlighted the potential benefits that users may gain from engaging in such behavior in multiplayer games. Beres et al. (2021) acknowledged the complexity of defining toxic behavior within the gaming community and illustrated that both players and game developers are committed to preventing such behavior, yet players who are exposed to it tend to perpetuate it.

Methods implemented on client devices to safeguard users from toxic behavior in online games are presented. Lee et al. (2021) presented for analyzing the protected memory area and the process of hacking programs in real time on client devices in order to protect users from toxic behavior in online games. The method was found to have high accuracy in detecting users utilizing the memory injection technique. Jeon and Kim (2021) proposed a client-side game protection mechanism based on ARM TrustZone technology for mobile games. This method was found to have no significant impact on performance and effectively detect common cheating techniques used in mobile games.

Various studies employ a range of features to detect toxic behavior in online games through analysis of in-game data. Tao et al. (2020) proposed techniques for detecting malicious behavior in games using explainable artificial intelligence (XAI). They assert their proposed method is highly efficient and can provide evidence and rationale for detection. Lee et al. (2016) presented a method for detecting game bots using self-similarity and tested this method using a large dataset from a massively multiplayer online role-playing game (MMORPG). Blackburn and Kwak (2014) developed a machine learning approach to detect ambiguous toxic behavior based on data collected from the "Tribunal," a community forum where players discuss and judge toxic behavior in "League of Legends." Canossa et al. (2021) presented a method for classifying malicious behavior through machine learning using a dataset from the game "For Honor." They defined different types of malicious behavior, such as "offensive behavior" versus "unfair advantage," and "warned" versus "banned."

Research has been conducted on the transmission of harmful behavior in online games, showing that the online gaming world is similar to society and has many psychological elements.

Zuo et al. (2016) found that cheating is more likely to affect other players when it goes unpunished. Woo et al. (2018) used data from massively multiplayer online role-playing games (MMORPGs) to demonstrate the social contagion of toxic behaviors, such as using game bots in online games. The study recommends targeted monitoring and selective bans to maximize the effectiveness of banning actions.

Data-Driven Approach

The method of detecting toxic behavior through data analysis can be applied to various online game security problems. By vectorizing player patterns, various analysis techniques can be employed to identify specific behaviors of interest, thus eliminating the need for ongoing rule creation and error correction. Additionally, the reporting system, which is a post-processing method that handles actions after they have taken place, but this method can detect and proactively respond to toxic behavior before it becomes a problem.

Feature Engineering

The data must be vectorized to utilize data generated within the game. Vectorization refers to the process of representing information as a list in which an order is established. There are various methods of vectorization, and the method employed depends on the characteristics of the data. One-hot encoding is a common method used for vectorizing categorical data. Only the domain's relevant features may be extracted, processed, and employed for vectorization. The resulting vector is utilized for a variety of analysis tasks.

Classification Using Similarity

There are many ways to represent a player's play patterns as vectors and subsequently classify them. (1) Euclidean distance, (2) Jaccard similarity, (3) Pearson correlation coefficient, and (4) cosine similarity are the methods. These methods can be employed to compare behavioral similarities and detect similar behaviors. Typically, behavior in games is represented as time series data. Thus, similarities can be determined by dividing the data into time windows of a specific size. The effectiveness of the method can be optimized by adjusting the manner in which the time windows are divided and combined.

(1) Euclidean distance is the coordinates of two points p and q in multidimensional space, respectively, $p = (p_1, p_2, p_3, \ldots, p_n)$ and $q = (q_1, q_2, q_3, \ldots, q_n)$. It is a method of calculating the distance between two points. The Euclidean distance formula is as follows:

$$d = \sqrt{\sum_{i=1}^{n} (x_i - y_1)^2} \tag{1}$$

(2) Jaccard similarity is a method for determining the similarity between two sets, A and B, by calculating the ratio of their intersection to their union. The Jaccard similarity has a value between 0 and 1, with a value of 1 indicating that the sets are identical and a value of 0 indicating that the sets have no common elements. The formula for Jaccard similarity is as follows:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|} \tag{2}$$

(3) The Pearson correlation coefficient is a numerical value that represents the linear correlation between two variables, X and Y. It ranges from +1 to −1, with a value of +1 indicating a perfect positive linear correlation, 0 indicating no linear correlation, and −1 indicating a perfect negative linear correlation. The Pearson correlation coefficient is calculated by dividing the covariance of the two variables in the data by the product of their standard deviations. The formula for the Pearson correlation coefficient is as follows:

$$r = \frac{\sum_{i=1}^{n} (x_1 - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n} (x_i - \overline{x})^2 (y_i - \overline{y})^2} \tag{3}$$

(4) Cosine similarity is a method that uses the cosine angle between two vectors to measure their

similarity. It ranges from −1 to 1, with a value of 1 indicating that the vectors point in the same direction, −1 indicating that they point in opposite directions, and 0 indicating that they are orthogonal. Cosine similarity only considers the direction of the vectors, regardless of their magnitude, making it suitable for representing play patterns that may vary in absolute value from game to game. The formula for cosine similarity is as follows:

$$\cos(x, y) = \frac{x \cdot y}{\|x\|\|y\|} \quad (4)$$

Clustering

Clustering is a machine learning technique that groups unlabeled data into distinct clusters or groups. This technique takes into account the characteristics of the data and aims to identify the central points that can represent each cluster. This method is useful for classifying users by their behavior in the game world. Typical clustering methods are as follows: (1) K-means clustering, (2) mean-shift clustering, (3) expectation-maximization (EM) clustering using Gaussian mixture models (GMM), (4) agglomerative hierarchical clustering, and (5) density-based spatial clustering of applications with noise (DBSCAN).

1. K-means clustering is a technique for identifying the closest point by selecting an initial random point and determining its centroid. The centroid is subsequently shifted to the mean of the selected point, and the process of selecting a point closer to the moving centroid is repeated.
2. Mean-shift clustering is an algorithm based on a sliding window to find a dense region of data points. It uses a circular sliding window of radius r centered on a specific point. Each step repeats the process of moving the window to find a region with a high density within radius r.
3. EM clustering using GMM addresses the limitations of traditional K-means clustering and offers increased flexibility. In situations where K-means clustering fails to effectively cluster data due to similar mean values, EM clustering using GMM assumes a Gaussian distribution for the data points. It employs the EM algorithm to determine the Gaussian parameters for each cluster.
4. Agglomerative hierarchical clustering has two categories: top-down and bottom-up. This method involves expressing the distance between data points in the form of a tree, which is then segmented into the desired number of clusters. The top-down approach begins by starting with a single cluster and dividing it into smaller clusters. In contrast, the bottom-up method starts with individual data points and merges them into one cluster.
5. DBSCAN is a clustering technique that utilizes the density information of the data. The algorithm performs clustering based on density and automatically determines the number of clusters, even for data sets with complex geometric distributions.

Conclusion

This entry has examined the issue of toxic behavior in online games and explored data-driven methods for its detection. While the presence of gray zone users in online games may not appear to be a significant problem, it is important to consider them to maintain a fair and clean gaming environment, as they can have negative effects on other players, such as causing offense and damaging reputation. By utilizing methods of user behavior analysis, it is possible to detect and prevent not only toxic behavior from *outside of games* but also that from *inside of games*. In order to obtain effective results, it is important to select an analysis method in consideration of the characteristics and context of the data.

Cross-References

▶ Artificial Intelligence
▶ Interaction

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Toy Computing

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Synonyms

Computing for smart toys

Definition

Toy computing is a recently developing concept which transcends the traditional toy into a new area of computer research using ubiquitous technologies. Toy computing incorporates the physical component of a traditional toy combined with networking and sensory capabilities of mobile devices.

Historical Background

Toys have been a part of human existence for thousands of years, across every culture, being uncovered from as far back as ancient Egyptian times. A toy is an item or product intended for learning or play, which can have various benefits to childhood development. Toys can have a variety of purposes including education, leisure, and socialization. As such a substantial part of the human development, toys have continued to

maintain a presence in the daily lives of billions of individuals of all ages. While primitive toys included rocks and pinecones, they soon progressed into dolls, stuffed animals, and trains. As new ideas continue to develop to reflect the era and culture, it becomes evident that the toy is a product which has evolved along with humankind. It has become a marketable product which has blossomed into a multibillion-dollar industry. Referring to the North American Product Classification System (NAPCS), toys are generally classified as electronic or nonelectronic. For example, the Tamagotchi, a handheld digital pet, is an example of an electronic toy, while dolls and stuffed toys are examples of nonelectronic toys. Electronic toys have gained popularity, consisting of electronic parts with embedded systems. In the past few decades, electronic toys such as Speak & Spell, Tamagotchi, and Furby had become popular. More recently, sensors and networking capabilities have introduced a variety of new possibilities for the toy industry. Toy companies have embraced modern technologies such as mobile devices into the design of their products, reshaping the concept of toys and education (LaMonica 2012) through mobile applications and augmented reality. Toys have evolved over the ages from simple dolls and cars to electronic toys and more recently have been integrating mobile technologies.

Current Scenario in Toy Computing

Toy computing is a recently developing concept which transcends the traditional toy into a new area of computer research using mobile technologies. A toy in this context can be effectively considered a computing device or peripheral. Toy computing is comprised of two main topics in computer science: physical computing and mobile services. Physical computing builds upon the traditional idea of the toy by bestowing it with potential embedded systems and sensory devices to create a more reactive and pervasive experience. Mobile devices act as the primary computing device and may also use sensors while hosting mobile applications and services which complement the physical device. Physical computing combined with mobile services can create an augmented reality environment for toy computing through which users can immerse themselves in the toy computing experience. Augmented reality is the result of overlaying virtual components which react to real-world triggers captured through cameras and/or other sensors. This is achieved through the combination of physical computing with mobile services. The toy may be endowed with sensory and/or networking capabilities, allowing for new opportunities for personalized services based on user preferences and environment. This introduces a service-oriented architecture (SOA) approach. One of the key concepts of this type of personalized services is contextual data. The application can gather data on the context of the user (e.g., time of day, location, weather) and provide personalized services based on this context data. Information security and privacy present unique challenges in toy computing, which introduces an increased risk with products exclusively marketed toward children, which have potential to collect large amounts of information through sensors and vocal interactions (Tang and Hung 2017). Toy manufacturers are increasingly incorporating emerging information technologies, such as services computing and virtualization technologies, into their toys in a bring your own device (BYOD) paradigm. BYOD is an emerging application distribution model that encourages players to use their own mobile devices such as smartphones and tablet computers to access various online and mobile services to interact with the toys and even other mobile devices. For example, Disney Dream Play is an interactive music toy that employs augmented reality technologies through a mobile app on a user's own device, providing the user with an enhanced experience as they interact with various Disney characters. In this context, toy computing is defined as a software development and distribution model based on services computing for mobile services in an autonomous environment, interacting with toys in compliance with not only the safety policy but also the new

cognitive measurement requirements in the BYOD paradigm. This new paradigm introduces a service-oriented architecture (SOA) approach in toy computing between the toys (service providers) and children (service requestors). Further to the SOA model, toy computing has also recently begun to utilize cloud technologies for features such as voice recognition, customized services, and storage for use with the toy applications. One example of this is the CogniToys Dino, which utilizes IBM Watson to provide answers to questions as well as age-appropriate games and learning activities. As embedded systems also continue to decrease in size and increase in processing capabilities, more functionality may be placed locally to the physical toy itself rather than externally. While other IoT devices within the home become more connected, the toys may interface with these as well, as suggested by the 2015 Google patent (US 2015/0138333 A1) where anthropomorphic characters such as toys act as interfaces for media devices within the home through social queues (Hung 2015).

Cross-References

- ► Children Privacy Protection
- ► Smart Toys

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Toy Privacy

- ► Children Privacy Protection

Tracking Techniques in Augmented Reality for Handheld Interfaces

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Synonyms

Augmented reality; Mobile interface; Motion tracking

Definitions

Tracking is a process to measure the camera's pose that needs to be aligned to the targeted pose estimation on real world. In handheld mobile AR, tracking technique has been facing its evolution from black and square markers detection, to feature tracking, and the topical is a motion tracking technique. Therefore, a comprehensive review in AR tracking techniques is provided particularly in handheld mobile AR including the recent motion tracking technique in sight.

Introduction

As agreed with Azuma (1997), the definition of augmented reality (AR) is consists of three main portions: (1) the fusion between real and virtual images, (2) running in real time, and (3) registered in three perspective world 3D (Azuma 1997; Krevelen and Poelman 2010; Mekni and Lemieux 2014). Recently, AR has been moving forward from desktop application to handheld mobile application. Handheld mobile AR interface

seems to be the main research area. Handheld mobile AR refers to handheld mobile video see-through AR that acted as magnifying glass that shows the real objects with an AR overlay that mostly based on existing consumer product such as mobile phones and PDAs (Krevelen and Poelman 2010; Mekni and Lemieux 2014; Möhring et al. 2004; Azuma et al. 2001). According to Schmalstieg and Wagner (2007), handheld mobile AR interfaces are more robust than head-mounted display (HMD) devices. AR gears such as HMD is not a new approach in AR where the user see-through the device's camera to observe the scene that enriched with virtual objects.

Nowadays, handheld mobile devices which are often referred to as mobile, tablets, or smartphones have been delivered to user with powerful processors, high-resolution cameras, and a range of sensors such as global positioning systems (GPS), accelerometers, and magnetometers (Kurkovsky et al. 2012). These components are appropriate to run AR system. The handheld mobile device is convenient to a personal use unlike other hardware and devices which may require users to carry or wear its special equipment. The AR application run in handheld mobile platform is portable and not constrained to any specialized area (Kurkovsky et al. 2012; De Sá and Churchill 2012). The demands for handheld mobile devices make it practical to enable AR technology to handheld users (Zhou et al. 2008) and so derive out different solutions to its components especially the tracking techniques for the registration process in handheld mobile AR. Consequently, in the rest of this entry, we first discuss each of the tracking technique implemented in handheld mobile AR presently. Next, we express the strengths and drawbacks of each technique theoretically and practically. Then, we summarized and compressed our comprehension through a table. We come to conclude in the last section.

Tracking Techniques in Handheld AR

Tracking technique is one of the fundamentals to enable AR technology (Zhou et al. 2008). It refers to the process that measures the rendering camera's pose that needs to be calibrated in order to report accurate pose estimates either using a physical video camera within an AR system or tracks a fiducial that is attached to an AR system (Kato and Billinghurst 1999; Grubert et al. 2017). AR is the technology that combines real and virtual objects in a single display. It overlays the virtual object into our real world in real time. There are three major AR requirements which are (1) tracking and registration (Bimber et al. 2005), (2) display technologies, and (3) real-time rendering. According to Höllerer and Feiner (2004), tracking techniques had been discussed under one of the main components of handheld mobile AR which is registration. Currently, there have two main categories of tracking technique: (1) marker-based and (2) markerless. Marker-based tracking always refers to existence of square marker with edge detection and registration of virtual content only valid when four vertices of a square marker are being identified (Mekni and Lemieux 2014; Schmalstieg and Wagner 2007; Yuan et al. 2005). On the other hand, markerless tracking refers to tracking techniques that are not based on artificial AR marker that has been created deliberately while using features that already existed in the real environment as AR marker such as painting book cover to register virtual contents. Recent natural feature such as human feature has been used as natural features for tracking purpose that is also known as marker hidden tracking techniques (Mekni and Lemieux 2014) that still need existence of real-world AR marker to register the virtual contents. However, markerless tracking also included motion tracking that uses the sensor such as gyroscope and accelerometer for tracking purpose; no prepared environments are required while virtual content is up to date based on the estimation from frame to frame (Mekni and Lemieux 2014; Schmalstieg and Wagner 2007).

Due to the trend of traditional AR to handheld mobile AR mostly implemented in mobile phones, the physical surrounding is represented on the screen by the live image of the back-face camera. Thus, spatial relation between the

physical surrounding represented by camera image and the on-screen contents is represented by displaying digital augmentation (Vincent et al. 2013); this information is typically gathered by a tracking system. The tracking system gathers information on the handheld mobile device's position and orientation and measures this information with respect to a model of the environment coordinate system (Kurkovsky et al. 2012). Failure of a tracking system may cause registration error that degrades user's AR experiences.

Generally, there have three types of tracking methods used in handheld mobile AR interface which are (1) marker tracking, (2) feature tracking, and (3) motion tracking. Both marker tracking and feature tracking are discussed in the following first two subsections. Motion tracking in handheld mobile AR on the other hand is the latest technology that is based on handheld mobile AR interface that tracks the tracking device's motion to register the 3D virtual contents and stated in the third subsection.

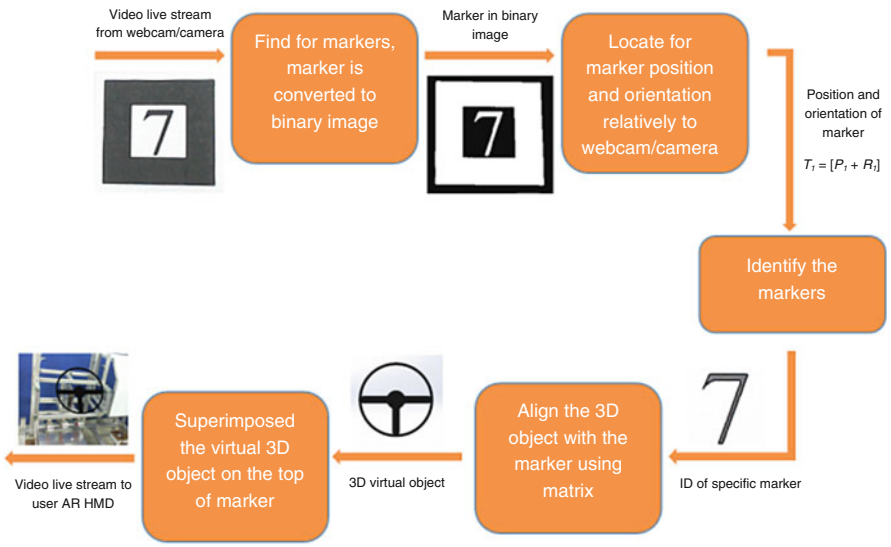
Marker Tracking Techniques

Marker tracking technique is a conventional tracking which refers to the method that a square marker of known dimensions is used to define the world coordinate system (WCS), and the camera extrinsic parameters, i.e., camera pose, are estimated using the four vertices of the marker to register the 3D contents (Yuan et al. 2005). At early stage, it refers to the square markers which are prominent in AR tracking technique (Zhang et al. 2002). In handheld mobile AR, the marker-based tracking is frequently being used. However, before AR, the usage of barcode (combination parallel line) and quick responsible (QR) code (two-dimensional barcode) as markers for vision-inertial tracking is widely explored. Since these types of markers are similar with the square, black and white AR marker thus have been reused in AR to correspond with AR tracking system. For example, Ruan and Jeong (2012) proposed to restructure QR code features stored as AR markers to develop an application in handheld smart device that can extend to many fields. Finder patterns (three position detection patterns) and alignment pattern which are the fixed information of a QR code are used for tracking purpose in order to register the virtual contents.

In the tracking process, detection of the marker is the first essential process. During the marker detection process, the camera first needs to be captured by the camera view and sent to the handheld mobile device's computational system. Algorithm is used to search through the video frame for any square marker pattern. Once a square marker is found and the image content embedded by the square shape which defined as finder pattern is matched and identified, calculation is computed both position of the marker and the pattern orientation relative with the camera and lastly the 3D content is drawn in the foreground of the captured video. Inertial tracking process is carried on against the movements of the background video causing the model to appear attached to the background (Fig. 1) (Coordinate Systems, ARToolKit Documentation, last accessed 2017/9/28). Figure 1 explains the basic principle on how the ARToolkit works from the camera and captures video of the real world and sends it to the computer firstly until the final output is shown back in the handheld mobile display; lastly, so when the user looks through the display, they see graphics overlaid on the real world. Examples of conventional tracking library are ARToolkit and ARToolkitPlus which extended from ARToolkit with ARTag, a fiducial marker system using digital techniques (Fiala 2005).

Feature Tracking Techniques

Feature tracking technique is one of the existing marker-based tracking techniques that are based on features such as points, lines, edges, or textures. In a feature-based tracking system, 2D features include geometrical primitives (points, segments, and circles) (Shi and Tomasi 1994), object contour (Isard and Blake 1996), region of interest (Hager 1998), texture (Bastos and Dias 2005), and edge (Kissling et al. 2012; Chen et al. 2016). In handheld mobile AR, the limitations of the processing power, when rendering virtual objects, require a lot of processing time. Thus, textured markers are used for handheld


Video live stream from webcam/camera
Find for markers, marker is converted to binary image
Marker in binary image
Locate for marker position and orientation relatively to webcam/camera
Position and orientation of marker
$T_i = [P_i + R_i]$
Identify the markers
ID of specific marker
Align the 3D object with the marker using matrix
3D virtual object
Superimposed the virtual 3D object on the top of marker
Video live stream to user AR HMD

Tracking Techniques in Augmented Reality for Handheld Interfaces, Fig. 1 Conventional tracking process (Chew et al. 2015)

mobile AR tracking purpose (Kissling et al. 2012). However, the direction of researches has moved from marker-based to markerless AR because of the existence of artificial markers in the real scene leads to the nonnatural perceptions (Pang et al. 2006; Kar et al. 2002). Nevertheless, the markerless tracking system that needs to track physical positions requires a powerful processor and computational system, yet at the moment, they are still too immature to be used in handheld mobile AR. Markerless AR refers to the artificial marker hidden techniques that track the natural features which are the parts existing in the real scene as natural markers (Comport et al. 2003; Souza et al. 2014).

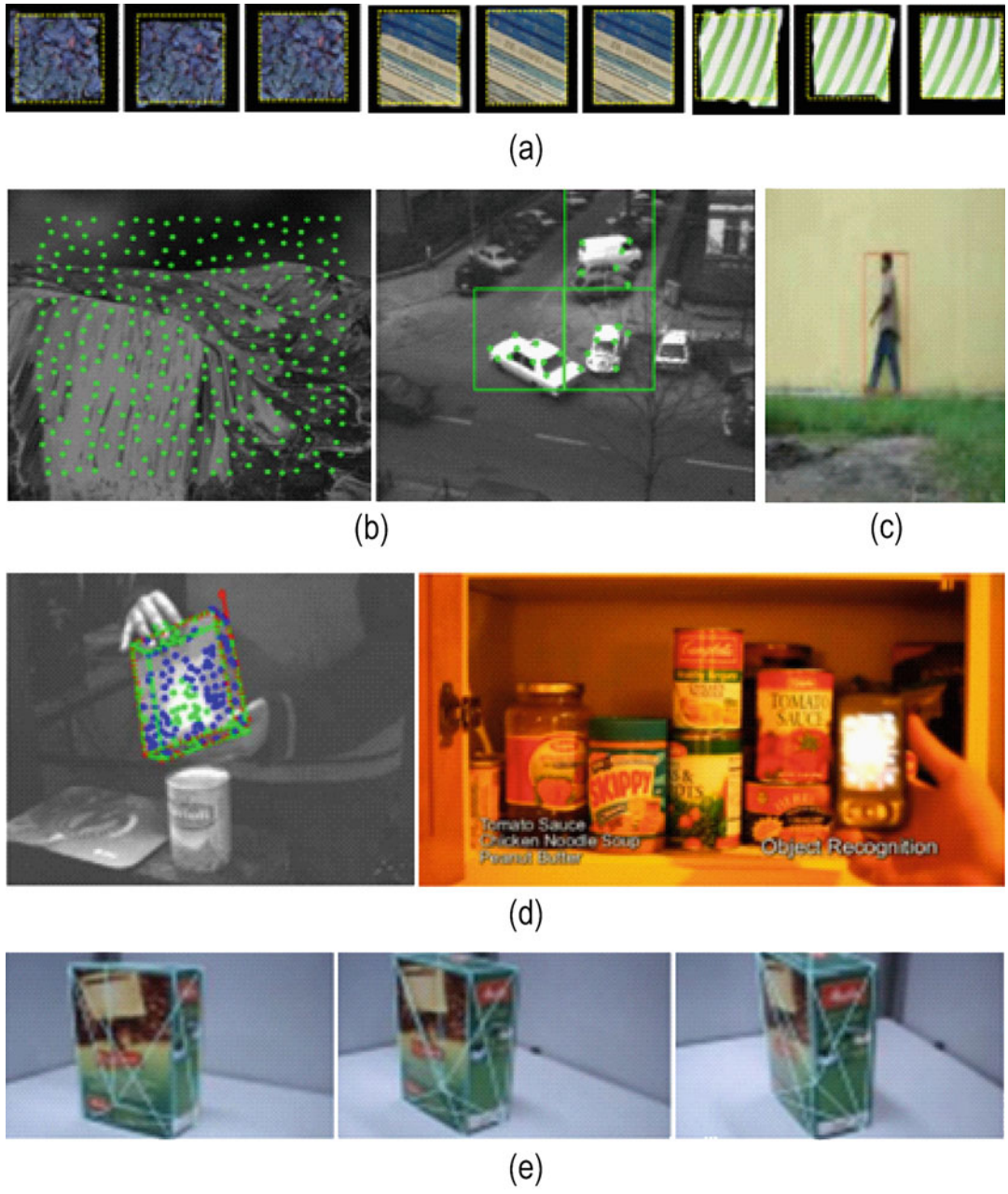
Examples of feature recognition used in feature tracking process are shown in Fig. 2. Vuforia is one of the tracking software development kits (SDKs) that are based on feature tracking. Vuforia is supported with natural feature tracking (NFT) and texture tracking library after both libraries are released in handheld mobile AR.

Motion Tracking Techniques

Motion tracking in handheld mobile AR usually is using visual-inertial odometry to estimate where a device is relative to where it started. Standard visual odometry uses camera images to determine a change in position by looking at the relative position of different features in those images.

Visual-inertial supplements visual odometry with inertial motion sensors capable of tracking a device's rotation and acceleration (Roberto et al. 2016). When the camera movement tracks the 3D space, it will continuously retrieve the coordinates and recursively updates the information of its current. In this case, its constant values are cue in stable motion, while it can be deferred, freeze, and move forward and backward. Thus, this indication presents the technique and computes the camera movement not in real time (Wagner et al. 2005).

In handheld mobile AR, one of the objectives is to render the virtual object in a real-world context with its accurate posture (Filippeschi et al. 2017). In order to actualize, AR system needs to know the position of the user, and this can be achieved in motion tracking by determining the motion of handheld mobile device itself supported with inertial odometry captured through built-in sensors such as accelerometer and gyroscope (Fang et al. 2017) together with the camera images to determine a change in position called



Tracking Techniques in Augmented Reality for Handheld Interfaces, Fig. 2 Examples of feature recognition for tracking purpose in AR system: (**a**) Kawai et al. (2017); (**b**) Neumann and You (1999); (**c**) Khandelwala et al. (2015); (**d**) Pressigout and Marchand (2006); Siltanen (2012); (**e**) Lima et al. (2010)

visual-inertial odometry (Lima et al. 2010). Visual distinct feature detection in the captured camera image is used to compute its change in location. Examples of SDK for handheld AR that are based on motion tracking are Tango (Marder-Eppstein 2016), ARCore (ARCore Overview, last accessed 2017/9/29), and ARKit (Introducing ARKit, last accessed 2017/9/29) shown in Table 1. Apart from motion tracking, ARCore and ARKit are available to understand the real environment through

Tracking Techniques in Augmented Reality for Handheld Interfaces, Table 1 General differences between Tango, ARCore, and ARKit

Aspect	Tango	ARCore	ARKit
Operating system	Android	Android	iOS
Additional depth sensor	Yes	No	No
Launching year	2014	2018	2017
Environment understanding	Depth perception	Surface detection	Surface detection
Mapping data	No	Yes	Yes

detecting horizontal surfaces or plane to register 3D content, while Tango required depth sensor to do so. Since the tracker motion had been used to estimate the 3D content's position and orientation without real-world AR marker, it can lead to a more reliable tracking process. Furthermore, mapping technique is utilized to estimate 3D content's position and orientation through localization of data set to retain more stable and smooth augmentation, while ARCore can manage larger mapping data set than ARKit.

In motion tracking system, the user needs to place the 3D virtual object to the real-world scene initially and adjust its vision projection based on user preferable perspective and the size of the 3D object she/he want to be displayed on screen through virtual camera. Smoothing tracking is then carried on supported by the inertial sensor to track the handheld mobile device's motion to update the perspective view of the 3D content. Though so, the 3D content rendered is not based on the real-world scene (Roberto et al. 2016; Filippeschi et al. 2017) but through the speculation on the device's motion. Real-time registration only occurs when the user placed the 3D virtual object to the real-world scene for the first time. None of continuous real-time tracking happens along the tracking process proved by the position and orientation deviations of the 3D virtual object that always happen in motion tracking system (Lima et al. 2010). Without the precise position, orientation and depth information for the 3D virtual content may downgrade the augmentation of the AR system.

Model-based tracking (Reitmayr and Drummond 2006) technique is another motion tracking solution for AR. In this approach, trackers will construct their models based on the lines or edges in the model. This technique has always been used for heritage conservation (Noh et al. 2009; Pivec and Kronberger 2016), for example, tracking a landmark by modeling it and saving it in the remote server to register virtual objects on a specific physical surrounding. Currently, this method has also been used for city planning purposes to ease the planning process through 3D modeling and reconstruct the buildings in the AR system (Santana et al. 2016). This approach requires a large use of memory, storage space, and the processing power of a handheld device to call out the 3D model store in the remote server and a long rendering time which is not generally used in handheld mobile AR.

Comparison of Different Tracking Techniques

The marker tracking and feature tracking techniques are both marker-based either artificial markers such as QR barcode marker or traditional square marker that used in marker tracking or natural markers such as texture marker that is represented by existing real-world features used in feature tracking. In both marker and feature tracking, position, orientation, and depth information for 3D virtual content can be captured through the calibration of the real-world marker tracked by the AR system mapped with the predefined attribute of the marker stored (Hager and Belhumeur 1998; Neumann and You 1999; Pressigout and Marchand 2006; Lima et al. 2012).

On the other hand, motion tracking techniques do not require the specific real-world marker to be tracked along the process. No artificial or natural

markers are required in motion tracking process. No calibration of depth/distance information is available without the existence of real-world-specific marker unless additional depth sensor is added such as infrared sensor (Vincent et al. 2013).

Without relying on the real-world marker, motion tracking system successfully comply coherence tracking to retain 3D content on its position and orientation that firstly is registered by estimating the virtual object position and orientation from the previous tracking device's motion that can reduce 3D content registration error unlike marker and feature tracking that require the real-world marker to be tracked consistently in real time to calibrate the position and orientation of 3D content in real world when marker is visible and within trackable range of view. Without real-world marker trackable, 3D content registration error may occur, and calibration is running consistently to register 3D content due to its real-time characteristic.

Based on the definitions of AR stated in several studies (Azuma 1997; Krevelen and Poelman 2010; Mekni and Lemieux 2014), it is clear that real-time rendering is one of the basic attributes of an AR system. In real-time system, response within specified time constraints, often referred to as "deadlines," is a must (Den-Ari 1990; Shin and Ramanathan 1994), while execution on certain tasks or process is needed to be completed within a regular interval. However, in motion tracking, the current position and orientation of virtual contents are estimated relative to where it started. A change in virtual content's position is simulated by looking at the relative position of different features in those images compared with the initial point. This characteristic supports the coherence tracking process which means its constant values are cue in stable motion, while it can be deferred, freeze, move forward, and backward that refer to non-real-time system (Ben-Ari 1990; Shin and Ramanathan 1994; Kejariwal and Orsini 2016) since these actions allow virtual contents to not update timely and disconnect with time constraints definitely offend the definition of AR system for real-time rendering and thus downgrade the augmentation. Oppositely, in marker and feature tracking, real-world markers are being used as the carrier to connect between real and virtual. 3D content is registered in real time with position, and orientation calibrated based on the tracking process through the connectivity on the real-world marker to provide realistic AR scene with high augmentation.

In motion tracking, since the changes in virtual content's position and orientation are simulated relatively to where it started though the estimation of the device's motion tracked by the inertial sensor to update the perspective view of the 3D content. Thus, there is no connectivity with the real world; the precision of the estimation through inertial sensor's information toward virtual content's appropriate position and orientation becomes a big question. Due to this issue, experiments had been made (Siltanen 2012), and the deviation of position and orientation of virtual object frequently occurred as stated in Siltanen (2012), while position deviations of virtual object registered happened every time it is updated based on motion tracking system. Unlike motion tracking, marker and feature tracking using the real-world marker in their tracking processes, 3D content position and orientation are calibrated synchronous each time marker being tracked therefore can register 3D content correctly without any deviation.

Practically, AR technology has been studied to be implemented in supporting several important sectors such as medical (Thomas 2016) and retail industries (Siltanen and Aikala 2012) assisting serious tasks such as surgery, training, and merchandising. These industries treat the accuracy and precision as the most important elements (Trevisan et al. 2008; Ponce et al. 2016). Without the connectivity with the real world (Vincent et al. 2013), motion tracking fails to provide precise information such as position, orientation, depth, and size information of the 3D virtual content that is important for those purposes. For example, in retail industries, AR technology is used to display retailed products in 3D virtual form to ease the potential client that may be interested on the

Tracking Techniques in Augmented Reality for Handheld Interfaces, Table 2 Comparison between marker tracking, feature tracking, and motion tracking techniques

Tracking technique	Marker	Feature	Motion
Use of artificial marker	Yes	No	No
Real-world marker based	Yes	Yes	No
Coherence tracking	No	No	Yes
Registration error	Possible	Possible	Less
Real-time tracking	Yes	Yes	Partially
Virtual object depth information	Provided	Provided	Not provided
Virtual object position and orientation deviation	No	No	Often occur
Practicality for serious tasks	Yes	Yes	No
Augmentation	High	High	Low

product but cannot reach the physical sales platform in trying the product through augmentation; thus, the size of the product and its depth in the real world are very important for the precise odometry and size estimation. In marker and feature tracking, depth information can be calibrated precisely through the real-world-specific marker. Meanwhile, the size of the virtual object can be pre-defined by mapping with the real-world marker. By standardizing the size of the marker, virtual object representing the real-world product can be drawn accurately retaining the same size; it should be in the real environments unlike the motion tracking system, and there is no connectivity with the real world and the system understanding the real-world environment by detecting flat surfaces existed in the real scene although the surface detected may be in the different size. Without the specification of the real-world planar, the size of the virtual object cannot be identified and thus impossible to provide the precise volume information (Roberto et al. 2016; Marder-Eppstein 2016).

After reviewing several aspects between marker tracking, feature tracking, and motion tracking, Table 2 shows the summary of the discussion above.

Conclusion

In conclusion, conventional tracking technique, feature tracking technique, and motion tracking technique have been reviewed in detail. Each technique has been discussed including its functionality such as its strengths and drawbacks. The comprehensive discussion is summarized into a table to provide a more obvious confrontation.

Conventional tracking still is widely used in AR system for different purposes. Its stability leads AR to be used in more serious industries. However, the naturality of this tracking technique needs to be improved to enhance user's AR experiences. Feature tracking uses the real-world features as marker to register virtual contents, it is more natural compared with conventional tracking, and the potential to be practiced in various tasks and industries as well as its stability makes it the most attentive tracking technique. Most of the researches related with tracking techniques are based on feature tracking. Motion tracking is a new trend after the release of Tango, an SDK of AR technology for handheld mobile device. Motion tracking technique provides a smooth tracking process in order to enhance user's AR experiences. Even so, without the connectivity with the real world, it is hard to be implemented for serious purpose except for entertainment. Furthermore, partial real-time tracking offends the AR definition where real-time attribute is part of AR and thus downgrades the augmentation.

Further researches are needed focus on the fundamental issues in tracking. Providing

smoothing tracking with less registration error and solving the occlusion problem still is the challenging issue in AR. In realize the seamless connection among virtual and real; still have a long journey need to be move on.

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Training

► Immersive Virtual Reality Serious Games

Training Spatial Skills with Virtual Reality and Augmented Reality

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Synonyms

3D Skills; Mental rotation; Spatial reasoning; Spatial recognition; Visualization

Definition

Spatial visualization was defined by McGee (1979) as "the ability to mentally rotate, manipulate, and twist two- and three-dimensional stimulus objects" (p. 896). Although, better visualization skills can be achieved through childhood education and skill training, researches show it is still possible to train spatial visualization skills with various types of exercises in adults. It is not a new idea to use educational games and computer software in the education and teaching of spatial skills (Wells 2003; Uttal et al. 2013; Anderson et al. 2003; Kaufmann et al. 2000). Researches show it is possible to use VR/AR platforms to improve visualization skills. VR/AR platforms are a part of digital media, and special applications which focuses on the instruction of the visualizations skills can be developed with the support of the features and attributes of this media. Current best practices show learning by doing and constructivist methodologies fits well with this platform (Edutrends 2018). Students' motivation to the instructional activities can be increased due to the rich features of the VR/AR learning environment which can lead to longer instruction times, higher frequencies of instructional sessions, increased self-confidence due to increased number of instructional scenarios experienced by the learner.

Introduction

Educators are mostly spending effort to improve performance on STEM disciplines. Increasing need to professionals who are educated in STEM fields is the driving force of this strategy. However, basic skills such as spatial visualization which is an essential skill to improve understanding and success in STEM fields seem to be neglected. There are supporting evidence that show better visualization skills can lead to a decrease in engineering dropouts and an increase in academic success. On one hand, research studies show spatial skill can be improved with a lot of different methods dramatically; on the other hand, VR/AR platforms are gaining importance in instruction and gaming fields. Therefore, in this article, the questions how spatial visualization skills can be improved with VR/AR applications, what are the basic concepts of the particular subject, and what empirical evidence comes from the current research studies will be answered.

In this article, first, several definitions and the components of the spatial visualization skills concept will be introduced. Second, main parameters, measuring methods and well-known tests to measure visualization skills, will be explained. Next, sex differences in spatial skills, one of the most well and frequently studied part of the visualization field will be under focus. Sex differences will be followed by improvability, malleability, or plasticity of visualization skills, which are under the specialty of instructional technology field, with an emphasis on the method – media debate, which is one of the most important subjects of the instructional technology profession. Since, all VR/AR applications contain special software and hardware components, categories and instructional software and principles of multimedia learning will support the instructional frame of the subject. Finally, current pedagogical trends of the VR/AR instruction will be followed by the

research results focused on training spatial skills with VR/AR applications.

What Is Spatial Visualization

Starting from the first quarter of the twentieth century, spatial visualization field is a hot topic in cognitive psychology research, but there seems no real consensus on the definition of "spatial visualization skills" (Sorby et al. 1999). Spatial visualization was defined by MCGee (1979) as "the ability to mentally rotate, manipulate, and twist two- and three-dimensional stimulus objects" (p. 896). In Assessing Women in Engineering (AWE) Project, Visual Spatial Skills Overview (2005), spatial ability was highlighted as "... the over-arching concept that generally refers to skill in representing, transforming, generating, and recalling symbolic, nonlinguistic information" (p. 2). According to Kosslyn, visual imagery means to create mental images of how objects look in real world, and to be able to manipulate and change properties, orientation, rotation, and scale of these mental images in the mind (Kosslyn 1995). **Maria Kozhevnikov's mental imagery laboratory defines the same concept on their web page (** 2018**) as** "the ability to process visual information about spatial relations between objects or their parts and, perform mental spatial transformations and manipulations" (page id: 9 – Research). Most of the times, terms visual imagery, 3D skills, visualization, spatial recognition, spatial reasoning, and many more has been used interchangeably to define whole or at least some parts of the field. The words ability and skill has also been used widely and interchangeably, although former emphasizes that these properties are associated with genetic inheritance but latter emphasizes on positive training effects on improving the particular property.

Several researchers propose different schematizations to represent components of spatial visualization field.

According to Mental Imagery and Human-Computer Interaction Lab of National University of Singapore, Department of Psychology (2018), visualization ability can be examined under two main headings: (1) spatial visualization and (2) object visualization. Object visualization can be briefly defined as the process of visual information related to the pictorial appearances of objects and scenes such as plans, elevations, and sections (Mental Imagery Lab 2018). MCGee (1979) discusses about (1) spatial visualizations; (2)spatial orientations, the ability to follow directions with respect to a street map or a building plan; (3) spatial perception, to determine the spatial relations with respect to the orientation of viewers own body; (4) mathematical ability; and (5) mental rotations skills to rotate a two- or three-dimensional mental image with mental processes. AWE Visual Spatial Skills Overview (2005) and Linn and Petersen (1985) emphasize three main components of spatial skills: (1) mental rotation, (2) spatial perception, (3) spatial visualization.

The visualization skills can also be divided into three categories according to visual scales. The situation (1) in which the observer is larger than the object; (2) the environment is larger than the object and observer is surrounded by the environment; and (3) the observer and the environment are stationary, and environment is perceived as a stationary image of the same size or larger than the observer but as if located farther away from the observer (Hegarty and Montello 2006). According to the classification of Uttal et al. (2013), the spatial skills can be described as a matrix of 2×2 dimensions with reference to the target object as (1) intrinsic, relations between the parts of the same object, and (2) extrinsic, relations among objects in a group, and with reference to the environment and the observer as (a) static and (b) dynamic.

How Spatial Visualization Skills can Be Measured

There are many tests developed to measure different parameters of spatial visualization skills. Some of the well-known examples among these tests are mentioned in the following. Purdue Spatial Visualization Test (PSVT:R) was developed by Guay in Guay 1976. Pychometric properties of

this test were later studied by Maeda et al. (2013). PSVT:R is a mental rotations test and mainly used to investigate relations between the academic success of the engineering students and their spatial abilities. Another test to measure mental rotations ability is Vandenberg–Kuse Mental Rotations Test (Vandenberg and Kuse 1978) which was developed in 1978 based on Metzler and Shepard (1974) geometries and redrawn in 1995 by Peters et al. (1995). Embedded figures test investigates how surrounding environment effects the perception of a single figure embedded in the environment (Witkin et al. 1977). Different versions of paper folding tests has been frequently used in which the participant have to find the unfolded appearance of a folded piece of paper which was punched holes on its surface after being folded (French et al. 1963; Kyllonen et al. 1984). There are several other tests which measure the visualization abilities including mental cutting tests (Tsutsumi 2004) and box folding and unfolding tests, which have been frequently used and studied in related literature.

Sex Differences

Researches on the sex-related differences on spatial abilities and the reasons of these differences are still a hot topic on the spatial visualization field. According to previous studies, spatial skills vary from person to person. Researchers hypothesized about the reasons of this phenomenon as social factors, childhood games and toys, hormone levels, frequency and genre of frequently played video games (playing 3D games improves MR skills), sports activities, musical instrument playing skills, and sex differences (Meyer and Koehler 1990; Cherney and Coaller 2005; Cherney and London 2006; Hyde 2007).

Usually, male outperform female on spatial rotations tests with time pressure. Mostly male performs better on tests which were administered by using computers compared to paper pencil tests. Although in some areas of visualization there is no performance difference between sexes, strategies while solving spatial problems can be different (Uttal et al. 2013). Some researchers, on the other hand, claims sex differences in spatial visualization ability is very little or nonexistent (Linn and Petersen 1985).

McGee (1979) highlights four factors to explain the reason of sex differences in spatial abilities. These factors are (1) environmental, (2) genetic, (3) hormonal, and (4) neurological factors. The hormonal factors mentioned here are estrogen and androgen levels. McGee's study showed that high androgen hormone levels indicate low spatial ability levels in men. He emphasizes the balance between estrogen and androgen rather than the level of the single hormone. Another factor, also called neurological factor, is related to the development of brain hemispheres. Since synaptic stabilization of the brain lasts mostly in the first 15 years of life, better visualization skills can be achieved through childhood education and skill training during the first 15 years of the life (Rakic et al. 2009).

Training of Spatial Skills

It is understandable that neurological factors have a clear influence on the spatial visualization ability. The question is, is it possible to improve spatial skills by training? Research studies clearly indicate that visualization skills are improvable by training. In a meta-analysis, it was shown that "even a small amount of training can improve spatial reasoning in both males and females, and children and adults" (Uttal et al. 2013, p. 370).

According to Sorby's explanation (Sorby 2009), spatial skills are developed in three stages. First topological skills, which are primarily two-dimensional skills, are acquired. With this skill, children recognize an objects position and relation among other surrounding objects. Typically children who can do puzzles use this skill. Second, children acquire visualization skills of 3D objects. With these skills, children can visualize mentally a 3D objects view from different viewpoints and how it will look like if the object is rotated or moved in space. Last set of skills to be acquired are related with area, volume, distance, translation, and reflection concepts.

Since, it is very easy to train visualization skills with or without instructional software, solid training can be achieved by administering treatments which includes eye-to-hand coordination like sketching 3D objects on paper. These activities include playing with construction toys, playing 3D computer games, joining sports activities, and studying mathematics (Sorby 2009). These activities include "(1) playing with construction toys as a young child; (2) participating in classes such as shop, drafting, or mechanics as a middle school or secondary student; (3) playing 3-D computer games; (4) participating in some types of sports; and (5) having well-developed mathematical skills" (Sorby 2009, p.461).

Covering the same subject, Uttal explains that various training activities can help develop spatial visualization skills, so there is not only one best training activity. Instead training activities must be developed and selected depending on the instructional goal, amount of time, and availability of resources (Uttal et al. 2013).

Designing of Instructional Software

It is not a new idea to use educational games and computer software in the education and teaching of spatial thinking In architecture and engineering education, it is possible to see research studies about experimental software specially designed to develop spatial visualization skills some with immersive VR systems (Wells 2003; Anderson et al. 2003; Kaufmann et al. 2000).

VR and AR applications, which focus on the instruction of the visualizations skills, can basically be classified as instructional software. Human computer interaction (HCI) and interface ergonomy are some basic factors to be considered. VR–AR systems require learners to wear specially developed headsets. Especially while experiencing VR environment, some users complain about dizziness and nausea due to the inconsistent sensory data coming from the muscle system, eyes, and vestibular system. Software designers must pay attention to the movement, acceleration, orientation, and rotation speed of the user while moving in VR environment.

Any instructional software must follow a systematic approach based on the type of the skills and knowledge to be instructed. According to Roblyer and Doering (2010), an educational software can be designed in five different categories. These are (1) drill and practice software for skill development, which allows students to solve a large number of problems or to answer questions and receive feedback about the correctness of their answers; (2) tutorial software that aims to give an education on its own without the existence of a teacher. These include real educational material to be learned by the student. These are self-driven software and student can adjust the pace of the instruction to be delivered; (3) simulation software, technological models of a real system or environment which show how a system works. By using simulations, students can get a real-world experience. These software are focused on instructing about the system itself by allowing students to study on scenarios created procedurally by the software or manually by an instructor who observes the student during simulation process, rather than general problem-solving strategies; (4) instructional games that increase the motivation of the learners by adding gamification, game elements, rules, competition, and entertainment factors to the learning activity and simulations; (5) problem-solving software aiming at acquiring analytical thinking of the learner, in which the knowledge and skill are necessary for solving a certain problem.

As VR–AR software is also a part of multimedia learning, designers must know about the 12 basic principles of this learning method. Richard E. Mayer (2002) lists these 12 principles in his book as (1) coherence principle; (2) signaling principle; (3) redundancy principle; (4) spatial contiguity principle; (5) temporal contiguity principle; (6) segmenting principle; (7) pretraining principle; (8) modality principle; (9) multimedia principle; (10) personalization principle; (11) voice principle; and finally (12) image principle.

Method–Media Debate in Instructional Technology Field

Thinking of instructional methodology, all digital instructional systems including all instructional software, hardware, and mainly VR–AR systems, are a part of digital media. It must be discussed carefully that either digital media (VR–AR) or instructional method is the key element in training visualization skills.

One of the main discussions in the field of instructional technology is the method–media debate which was between Richard Clark and Robert Kozma and has been started in the early 1990s. According to Clark (1994), media has no influence on the learning and media is only a vehicle that delivers instruction to students. Media attributes (symbol systems like zooming into details, animations, highlighting details, etc.) are the surface features and the instructional method (learning by doing, project-based learning, etc.) chosen for the specific type of instruction is the main structural feature that influences learning. Clark claims "there is strong evidence that many very different media attributes accomplish the same learning goal" (p. 22). This means all media attributes are replaceable with some other attribute to achieve same learning gain, so media attributes are proxies of some variables of learning gain (Clark 1994).

Clark (1994) links the debate to various cost-effectiveness levels of various media. He claims an instructional designer must choose the less-expensive and cognitively efficient (easy to learn, fast, and permanent instruction) way to deliver decided instructional method. Therefore, a designer must be aware of certain media attributes which can be more effective, efficient, and easier for various learners and tasks.

Pedagogical Trends and Benefits of VR/AR in Instruction

AR and VR technologies can be used as the media to deliver traditional instructional methodologies. Students' motivation to the instructional activities can be increased due to the rich features of the learning environment (Edutrends 2018). This kind of a learning environment allows learners to interact with the immersive environment and the virtual objects in the simulations, and actively manipulate the virtual surrounding to study on possible solutions of the problems which are a part of the immersive learning experience rather than passively listen or watch the instructional content. Therefore, best instructional practices experienced with the VR/AR media are based on the constructivist instructional approach applied with learning by doing methodology (Edutrends 2018).

As it was reported in Edutrends (2018), some of the outstanding pedagogical trends of VR/AR instruction are: (1) conventional educational material which are being converted to digital educational materials to be used with VR/AR; (2) using the instructional capacity of games by creating gamified instructional material, as "[...] experimental studies indicate that playing computer games engage the dopaminergic brain reward circuit, [...] the rewards that we get from computer games are not any less real at the neurobiological level" (Balkaya and Catak 2016, p. 28); (3) VR/AR environments make it possible for learners to experience lifelike simulations, learning scenarios can be created based on experiment-based learning strategies; (4) by using the advantages of wireless internet connection almost anywhere on the world, learners can decide whenever and wherever they want or need to be trained; (5) instead of a learning experience without the existence and feedback of an expert observer, blended learning, which is supported with immediate presence and mentoring of an expert observer or teacher is suggested; (6) with easy-to-use developing tools, even learners can design and create their own learning experiences.

Although it is very early to talk about the existence of solid learning benefits of VR/AR media, Edutrends (2018) reports that six benefits seemed to be frequently presented in the current literature. These are; (1) VR/AR systems can stimulate attention more as they sends more sensory input, but this can also lead to a caution that too much stimulation can create an overload and reduce the attention; (2) immersive environments

seem to have positive effects of long-term remembrance of learned materials due to the fact that they allow the learner to live the experience in the context, which can lead to a better memorization of the learned material; (3) efficient learning pace, which learner can adjust the learning pace for her capacity; (4) immersive environments make it possible for learners to live in the simulations so that learners can participate in the learning experience rather than listening or watching the theoretic content; (5) research studies show VR/AR technology has a positive effect on motivation of learners; (6) VR/AR platforms, not different than some other existing digital learning platforms, presents the possibility of personalization of the learning experience by the learner, so that learner can adjust the activities, performance, and difficulty of the learning experience.

Training Spatial Visualization Skills with VR/AR: Evidence from Research

Very little or no systematic research work has been done to study the effects of VR/AR systems in training spatial visualization skills. There seem no commercial VR/AR applications developed to use for this training purpose either. Lightweight, cheap immersive VR/AR headsets were introduced in the middle of the second decade of 2000s. Probably, for this reason research teams have not been adopted these new technology headsets as research tools yet. In literature, mostly VR abbreviation means a VRML system running on a desktop computer equipped with 2D monitor. However, new technology lightweight VR/AR headsets can provide the immersion effect. Even with a newer technology, which is called mixed reality, user can walk through the virtual holograms which are floating in the real environment. So the participant can generate more precise sensory input coming from muscle, vision, and vestibular systems compared to the sitting experience of the VRML-like systems running on 2D computer screens. Only some research studies used active glasses to simulate the immersion effect. In some medical studies, immersive VR and mixed reality systems have been started to be used for training purposes of surgeons but these studies mostly are not targeting to measure the effects of spatial training with VR/AR devices. Neubauer et al. emphasize that "the well-documented sex difference in mental rotation favoring males has been shown to emerge only for 2-dimensional presentations of 3-dimensional objects, but not with actual 3-dimensional objects or with virtual reality presentations of 3-dimensional objects" (Neubauer et al. 2010, p. 2). Various studies show, studies made by video games (2D and nonimmersive 3D) can improve spatial skills, especially mental rotations, with training effect.

In a brain activity study researchers studied, in a pretest–training–posttest design, the combined effect of a training which lasted 2 weeks on mental rotations ability by using two-dimensional versus three-dimensional presentations of the Shepard–Metzler (Shepard and Metzler 1971) task. Research team assigned these 38 male and 39 female participants (age 15) and their accompanying cortical activation patterns assessed via EEG. They used active glasses to create a semi-immersive 3D effect. Research shows in 3D presentation of mental rotations task, reaction times of participants are shorter. With training, reaction times become even significantly shorter, and researchers witnessed no significant sex difference in reaction times. After analyzing scores, researchers found sex differences of males outperforming females in the 2D-presented version of mental rotation task, but not in the 3D-presented version. Additionally, they showed sex difference diminished after training. In neurophysiological sense, it seemed there is a decrease of brain activity after training for male participants, meaning increased efficiency in both 2D and 3D tasks, but for females this increase of efficiency is only in 3D mental rotation tasks (Neubauer et al. 2010).

In a study conducted in the engineering graphics field, researchers measured the improvement of spatial ability by using nonimmersive VR and AR instructional software. In this study, researchers planned to measure three parameters: spatial relations, spatial visualization, and spatial orientation. First two parameters were trained by

using the AR software and the last one trained with the nonimmersive VR software, which is actually a gamified simulation of a sport called orienteering. Control group got no instructional treatment. Measuring spatial orientation is not a very frequent practice. The researchers concluded that the training experiment shows the three components of spatial ability were improved significantly compared with the control group (González et al. 2017).

In an experiment conducted in architectural education field, participants said to reconstruct a volume by using plan and side views by using real or virtual cuboid objects in real-world, nonimmersive virtual environment, and immersive virtual environment. The result of the study shows although designers studied with 2D presentations of a 3D volume as the predominant medium to understand the spatial arrangement of cuboids, their 3D spatial understanding is improved with immersive VR instruction. In architecture field, immersive VR systems are mostly used for presentations. This study shows these tools, which can enhance perception and understanding of 3D volumes, can be used in the architectural design process (Schnabel and Kvan 2003).

In another study, a desktop VR (as VR also covers nonimmersive 3D desktop environments without a headset) environment is used. Researchers studied on 33 secondary school students grouped into three as interactive treatment group, animation treatment group, and control group. All groups trained on same exercise sets and interactive group studied with a software in which they can interact with the objects, animation group only watched the blow-up animations of the exercises, and finally control group studied with the classical pencil paper methods to train. Results show that all students showed some level of gain in all treatment groups. In more detail, male and female students of the interactive group showed the most improvement gain, animation group showed moderate gain and poor gain in conventional group. In general, male students achieved higher gains compared to female and sex difference in gain was the most in interactive treatment group. Female students, however, improved in all groups but less than males irrespective of the method used (Rafi et al. 2008).

In a study of a similar kind, three treatment groups were studied. First treatment group was trained with a nonimmersive desktop VRML application, second group used a desktop AR application, and last group used PDF3D application which has the ability to view 3D objects embedded in PDF files. Control group did not get any kind of training. All groups' participants used applications to view 3D objects from any viewpoint to understand the 3D geometry of the object without having the real object in their hands and sketch the workshop contour plan by hand. Results were measured by using a pretest posttest pattern. Results show all treatment groups show almost same level of significant improvement and control group has almost no improvement (Martin-Gutiérrez et al. 2013). This can be a result of the similar instructional methodology (sketching a 3D object on a paper by hand which was shown on a 2D monitor) in all groups although the media is different (VRML, AR, and PDF3D).

These examples show spatial abilities can be trained in both males and females with special training or with everyday activities. These effects, training durations, activities, and strategies can differ from person to person and among sexes, but it seems males benefit faster from the instruction and training especially in 2D mental rotations tasks. Immersive VR can be used to train spatial visualization skills of both sexes and it must be remembered that the training activity is the decisive element of the training thinking about the efficiency of the skill gain rather than the presentation mode (2D and 3D). Finally, mental performance of mental rotation tasks is dependent strongly to the representation mode among sexes.

Conclusion

In this article, essential information about improving visualization skills by using VR/AR platforms, and background information about related fields and evidence based on current research studies was covered. Since, it is very easy to

train visualization skills with or without instructional software, solid training can be achieved by administering treatments which includes eye-to-hand coordination. These activities include sketching 3D objects on paper, construction toys, playing 3D computer games, joining sports activities, and studying mathematics (Sorby 2009). VR/AR platforms are very convenient to develop applications which can include and simulate these kinds of activities due to their immersive nature. Evidence shows it is possible to improve visualization skills by using VR/AR platforms. However, designers ought to remember that VR/AR systems are a part of media and they merely deliver the instruction or drill which was designed by the instruction designer based on the selected instructional method. Therefore, the instructional method (not the platform or hardware) which was objectified as the application and delivered by the hardware is the main structure of any improvement in the visualization skills.

Cross-References

- Augmented Learning Experience for School Education
- Cognitive Psychology Applied to User Experience in Video Games
- History of Virtual Reality
- Immersive Technologies for Medical Education
- Immersive Virtual Reality Serious Games
- Interactive Augmented Reality to Support Education
- Redesigning Games for New Interfaces and Platforms
- Virtual Reality Applications in Education

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Transformational Games

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Synonyms

Educational games; Game-Based Learning (GBL); Games for health; Serious games

Definition

Transformational Games are games developed with the intention of changing players in a specific way that transfers outside of and persists beyond the game. These games can be digital, analog, or both.

Term Origin and Relation to Other Terms

The term "transformational game" was coined by Jesse Schell after his studio's work on a variety of games that were designed to transform the player in a positive way but did not quite fit within the popular "educational game" category (Schell 2013). Educational games (Gredler 1996), serious games (Wilkinson 2016), game-based learning (Plass et al. 2015), games for learning (Clark et al. 2013), etc., are all popular terms used to describe games that aim to positively impact the player. Schell's game studio, Schell Games, uses the term "transformational games" to describe their work on a wide range of projects designed to transform a variety of players in specific ways, including but not limited to:

- Educational Games: Typically refers to games used in a classroom context or to teach

concepts usually encountered in classroom contexts (e.g., Dragon Box by WeWantToKnow)
- Games for Health: Typically refers to games that support player health or health habits (e.g., Re-Mission by HopeLab)
- Impact Games/Social Good Games/Games for Change: Typically refers to games that promote player engagement in social issues (e.g., Phone Story by Molleindustria)
- Training Simulations: Typically refers to games which replicate real-world conditions and scenarios for player practice (e.g., HoloLAB Champions by Schell Games)
- Behavior Change Games: Typically refers to games which try to change player behavior and choices in the real world (e.g., SuperBetter by SuperBetter)
- Empathy Games: Typically refers to games which use narrative-driven experiences help players identify with an issue or group by evoking an emotional response (e.g., We are Chicago by Culture Shock Games)
- Citizen Science Games: Typically refers to games which allow players to contribute to real-world research or tasks (e.g., Foldit by University of Washington)
- Serious Games: Typically refers to games that tackle training or education in real-world industries such as defense, education, science, healthcare, engineering, etc. (e.g., At Risk by Kognito)

These terms often overlap with one another, partly because each carries with it specific connotations about the type of transformation it is designed to engender and/or the contexts in which it is applicable. The umbrella term of "transformational games" connects these different game types under their shared major attribute of targeting player change, regardless of context, topic, aesthetic, mechanics, or audience.

Broad Definition of Transformation

Transformational games deal with a wide range of potential impact on players and, therefore, are used in a variety of contexts. For example, transformational games intended for use in educational contexts (e.g., formal learning environments like classrooms) are often focused on changing a player's knowledge or skills for the purposes of improved academic performance, whereas transformational games intended for use in healthcare contexts are often focused on behavior or physical changes in players for the purpose of improved bodily or mental health. Still other transformational games that address social issues may target changing player beliefs or dispositions for the purpose of societal improvement. A nonexhaustive list of types of player transformation that transformational games can target includes the following (Culyba 2018, p. 90):

- Knowledge: The player knows something new (e.g., player can recall the meaning of vocabulary words)
- Skill: The player can do something new (e.g., player can solve algebraic equations)
- Physical: The player's body is changed (e.g., player has a lower resting heart rate)
- Disposition: The player's feelings are changed (e.g., player's feeling of stress is reduced)
- Experience: The player's personal anecdotes are changed (e.g., player has experienced what it's like to face discrimination)
- Behavior: The player acts in a new way (e.g., players choosing healthier foods to eat)
- Belief: The player's sense of truth is changed (e.g., increasing players' belief that human trafficking is a big problem worth tackling with urgency)
- Relationships: The player's social relationships are changed (e.g., getting players to have more trust in authority figures)
- Identity: The player's sense of self is changed (e.g., player starts to describe themselves as 'artistic')
- Society: The world around the player is changed (e.g., increasing overall voter turnout in a community)

Example Usage Patterns

Transformational games can be used in a wide variety of ways. Some typical contexts and play

patterns are as follows along with hypothetical illustrative examples. Not all games fit cleanly into one of the categories below, but this list provides a general overview.

- A game designed to introduce a concept for later discussion or to reinforce topics introduced by an instructor. Games used in this way are meant to be augmented with supporting materials outside of the game. For example, consider a narrative game developed for high school students that is meant to be integrated into a school health class. The game's storyline showcases several healthy and unhealthy relationship behaviors. After students play the game on their own, the class has a teacher-facilitated discussion about how to recognize and handle the sort of relationship issues illustrated during the game. The choices that students made in the game offer a tool to drive reflective discussion and debate.
- A standalone game designed to include built-in curriculum that provides overt instruction to the player. For example, consider a game that teaches about green building practices by directly instructing the player on these practices and tasking them to create virtual buildings with mechanics that model real-world construction materials and processes. The game provides feedback on the player's performance with more tips and information on environmentally friendly construction.
- An exploratory game that supports learning driven by player interactions rather than direct instruction. This type of game may still be based on curriculum but is likely less structured in the way it presents information to the player. For example, consider a fishing game that requires players to complete tasks related to fishing to progress through various levels. The game contents and mechanics are based on real-world fish and fishing practices, but the game does not provide up-front instructions to the player regarding which foods or techniques work for which fish. Instead, the player learns successful fishing strategies (and thus facts about real-world fish and fishing) through in-game experimentation, failure, and success.
- A "head-fake" game in which the transformational intent of the game is obscured from the player. For example, consider a game that advertises itself as an augmented reality treasure hunt in which players must catch ghosts floating around the city. The ghosts appear on sidewalks and begin moving when players get close to them, forcing players to run after them. Unbeknownst to players, the game was funded by an advocacy group for heart health as a campaign to encourage teens and adults to spend more time moving outside to improve their health.

Impact on Development

What distinguishes the development of transformational games from the development of traditional entertainment games is the emphasis on impacting the player outside the game. In traditional game development, the focus is primarily on game appeal (i.e., what draws players in) and player engagement (i.e., what sustains players' interaction with the game). Transformational game development adds an additional focus on the player's interaction with the world outside the game. As defined previously, transformational games attempt to create a specific change in players that transfers and persists to the players' interaction with the real world outside the game. "Transfer" here is the application of player change from the game experience to the real world (i.e., generalization), while "persistence" is the continued manifestation of the player change after the game experience is over (i.e., maintenance).

There are many examples of games initially intended only for entertainment that have been adapted for a transformative purpose. For example, Minecraft has been adapted to tackle many classroom topics. Transformational games are generally distinguished from these adapted games, though, because of the nature of their development processes (i.e., transformational game development includes intentional design to target a specific impact on players; see Culyba

2018 for additional detail). Specifically, transformational game development often includes:

- Additional considerations of the audience and context that the game must address (e.g., integration into classrooms)
- Establishment of transformational goals that express the impact the game aims to have on individual players (e.g., players reduce their smoking habits after playing the game)
- Analysis and design accommodations for barriers that impact player transformation (e.g., if players lack or need a refresher on some basic math skills which impede their learning more advanced topics, game developers can include in-game scaffolding for assisting players with those prerequisite skills)
- Inclusion of real-world domain concepts related to the game's topic (e.g., foreign-language vocabulary)
- Collaboration with subject-matter experts (e.g., a teacher or researcher who works professionally within the game's topic)
- Leveraging academic research as basis for the game's design (e.g., using research on the impact of peer accountability to design multiplayer features for a game to improve exercise adherence in players)
- Assessment of the game's efficacy (e.g., have players take a test before and after playing to measure the game's impact; see more below)
- Emphasis on feedback to player (or other stakeholder such as a teacher) about the player's transformation
- Consideration of funding through grants or nonprofit channels
- Accompanying supporting materials for use outside the game (e.g., documentation for teachers or debrief materials for players)

Assessment

The logical next step after designing and developing a transformational game is assessing the game's impact on player transformation. The simplest assessments (e.g., player self-reports of learning or behavior change) require few resources but only allow for anecdotal rather than causal evidence. More complex assessments (e.g., randomized controlled trials) require more resources but allow the developer to make causal claims about the game's effectiveness. In other words, the easier the assessment, the less conclusive the data, but the more difficult the assessment, the more conclusive the data.

Game development teams typically conduct informal assessments (i.e., playtests) throughout game development to obtain feedback on a variety of game characteristics (e.g., gameplay mechanics, usability of controls, likeability of characters, etc.). Conducting these playtests early and often is essential for creating an engaging experience for the target audience. In some cases, development teams can assess portions of the game or a mini-game experience that is part of the larger game for effectiveness during development, which allows the team to make changes to improve effectiveness prior to locking in game mechanics. This process can be more time- and resource-consuming than many development budgets can handle, though. More typically, formative testing (e.g., focus groups; Thompson et al. 2010; Hieftje et al. 2012) gathers input from essential audiences that developers incorporate into the game in order to increase the likelihood of transforming players as intended.

Post-development assessment teams typically conduct formal evaluations of the final product as it will be deployed to determine the extent to which player transformation occurs as related to gameplay. A rigorous experimental evaluation can answer many questions using a variety of methods (e.g., group designs [e.g., Mohan et al. 2017], single-subject designs [e.g., Joyner et al. 2017]) but can fit into two general categories: (1) did playing the game cause a player transformation? (e.g., Riconscente 2013) and (2) how does the transformation that the game caused compare to other interventions designed for the same purpose? (e.g., Castellar et al. 2015). Answers to both types of questions provide useful information, though the types of measures (and thus claims that can be made) vary widely based on the research methods used. The former

approach provides evidence that a game makes a change in a player, and the latter, comparative approach provides a more complete picture and justification for developing, implementing, and maintaining a game because of its comparative nature. If an objective evaluation shows that a transformational game not only achieves its goals but achieves them in a faster, more efficient, and more engaging way than the status quo, it may become easier to support widespread implementation and dissemination and subsequent resources for future projects.

Conclusion

The term "transformational game" encompasses the wide variety of descriptors for games designed with the purpose of changing the player in a meaningful way. Transformational games can be powerful tools for making many types of changes in many types of players, but developing and evaluating transformational games requires a large number of considerations.

Cross-References

- Challenge-Based Learning in a Serious Global Game
- Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being
- Educational Virtual Reality Game Design for Film and Animation
- Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay
- Games in Science
- Gamification and Serious Games
- Hypermedia Narrative as a Tool for Serious Games
- Immersive Virtual Reality Serious Games
- MEEGA+, Systematic Model to Evaluate Educational Games
- Mindfulness, Virtual Reality, and Video Games
- Narrative in Video Games
- Psychological Game Design
- Rehabilitation Games
- STEM Learning Through Video Games
- Videogame Engagement: Psychological Frameworks

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Transformative Games

▶ Public Health Education via Computer Games

Transmedia Storytelling

▶ Five Nights at Freddy's, a Point and Click Horror Game

Troll

▶ Video Game Trolls and Dopamine Withdrawal

Trolling

▶ Video Game Trolls and Dopamine Withdrawal

Trustworthy Autonomous Vehicles

▶ User Interface (UI) in Semiautonomous Vehicles

Trustworthy Embodied Virtual Agents

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Synonyms

Embodied virtual agents, often abbreviated to EVAs, are computer-generated characters built to replicate the likeness of humans. The term is synonymous with 3D humans, virtual humans, embodied conversational agents, and digital avatars.

As a general descriptor for a collection of approaches, the term *ArtificialIntelligence*, commonly shortened to AI, is synonymous with various terms describing intelligent computers.

Trustworthy AI is a term used to describe Artificial Intelligence that is lawful, ethically adherent, and technologically robust. The idea is to provide AI systems with the capability to enhance and expose their trustworthiness toward humans.

Definitions

Despite the countless synonyms, *EVA*s are a general term for virtual human-like agents, with the various interchangeable synonyms utilized to describe some nuanced feature bestowed upon a virtual human, i.e., language understanding for conversational agents.

AI is an umbrella term for a collection of approaches that aim to distill intelligence within a machine. It encompasses specific approaches such as expert systems, machine learning, and deep learning.

Trust has many definitions, each tied to reasoning about *what* can and cannot be trusted. The decision perspective of trust can be defined as putting another in control of an uncertain outcome, thereby accepting risk given some context and predisposition to trusting others.

Embodied Virtual Agents

Embodied virtual agents (EVAs) are computer-generated characters built to emulate the behavior or appearance of humans and other beings. A term confusingly synonymous with many other terms (Lun 2011), EVAs are an umbrella descriptor for digital avatars, virtual humans, and virtual agents. However, using these alternative definitions commonly ascribes some nuanced feature or quality. Despite the difficulty in ascertaining concreteness with the many bundled descriptors, the lack of clarity infers the many applications and domains EVAs are deployed. The exact terminology

somewhat obfuscates the discussion, but the flexibility of the terms reflects the many techniques, problems, domains, and applications to which they are applied. For this article, the assumptions made when discussing EVAs will indicate the former, a virtual human-like agent. This distinction carries both a modern relevance and historical weight, with myth, history, and literature beguiled by the creation of artificial humanoids; Talos, Frankenstein's Monster, and Čapek's robots. While the desire to emulate human behavior and intelligence is one of antiquity, its realization (or at least partial realization) is a capability of modernity. Artificial intelligence has undoubtedly proliferated the application of EVAs across many domains. Whether deployed as new methods of HCI (Pustejovsky and Krishnaswamy 2021), conversational chat-bots (Traum 2008), or computer game characters (Lankes and Bernhaupt 2011), AI-assisted EVAs appear to be inescapable. W*hy is this?* Data availability, hardware advancements, funding, and hype have perpetuated Artificial Intelligence. Although many EVAs are developed symbolically, deep neural networks have facilitated a wave of features for EVAs to utilize. The most commonly discussed are the conversational agents that utilize Natural Language Processing (NLP), speech recognition, or rule-based responses, with many more incorporating subtle conversational elements under the umbrella of affective computing (Artificial Emotional Intelligence). EVAs have since adopted alternate methods of enhanced interaction, able to use non-verbal cues to identify gestures (Gris et al. 2015), to which they respond accordingly. This small sample of features highlights the difficulty in concretely defining an EVA, with many interchangeable interaction methods and countless overlaps across similar research, albeit without the distinction of a virtual human.

Trustworthy AI

Despite being an overloaded term, for the purposes of this report, *trust* will be defined as a mechanism to accomplish a goal between two or more parties in which the situation is underpinned by uncertainty and risk (Lewis and Marsh 2022); a definition grounded in the works of Gambetta (1990), Luhmann (1979), Marsh (1994), and McKnight and Chervany (1996). This distinction has been aptly expressed as a *cell membrane that protects. . . from outside forces by selectively letting in substances* (de Visser et al. 2012). Nevertheless, it remains a complicated term because of the many disciplines to discuss it. The digital world and the advent of cognitive agents have somewhat fragmented its understanding, with many unsure *what* can and cannot be trusted. As condensed by Lewis and Marsh (Lewis and Marsh 2022), four distinct perspectives can be ascertained; Accountability, Coordination, Goodwill, and Decision. The first two positions: Accountability, and Coordination, can be streamlined to conclude that only humans can be trusted. As Lewis and Marsh argued, Bryson (2018) sits within these perspectives, a proponent of the view that trustworthiness should not, or indeed cannot come from AI but from institutions and individuals. Next, the Goodwill perspective permits trust for sufficiently intelligent beings (including some AI), and finally, the Decision perspective establishes trust as a decision heuristic that applies to any object. As a decision heuristic, trust can be described as putting another in control of an uncertain outcome, thereby accepting risk given some context and predisposition to trusting others. Given its reliance upon situational context and personal predisposition, trust can be described as temporary or provisional (Dwyer 2011), specific to an individual (Dwyer et al. 2013). Trustworthy AI is not a new term, but recent developments like the EU's *Ethical Guidelines for Trustworthy AI* have forced the discussion to the forefront (2019). Despite its newfound popularity, it remains a complex and contentious area for discussion for AI. AI is itself contentious, often oversimplified, and commonly misunderstood. AI is a multifaceted umbrella term for a collection of techniques and approaches. So when one asks, "Do you trust AI?", how can another answer, given AI's many meanings and potential uses?

Evidentially, trust must be considered given the context to which it is applied. *For example, "do you trust AI to autocomplete your sentence?"* and "*do you trust AI to manage a nuclear arsenal?"* would undoubtedly involve two distinct sets of reasoning criteria for a trust decision. So why rely upon asinine questions about the totality of AI? The intent of these questions may appear benign. However, they demonstrate the desire of technologists to compel individuals into trusting AI (Ryan 2020). Examples of egregiously loaded language reinforce this belief (Enkel 2017), enabling trustworthy AI to become another buzzword for selling software. Gaining trust through similar means is defined as trust enforcement (Dwyer 2011). This distinction highlights how persuasion can convince another to make a decision they would not have otherwise. Conversely, trust empowerment provides an individual with the information to make trust decisions with no bells and whistles; it is about transparency, understanding, context, and the individual's predisposition to trust. Empowering trust decisions is integral for the intersection of AI and society, with the many horror stories of biased and inaccurate algorithms signifying their worth (Buolamwini and Gebru 2018; Cooper 2018). As the features embedded within EVAs become more advanced, endowing them with immense capability, the domain of trustworthy EVAs will undoubtedly become an increasingly prominent topic. The primary justification is that the features built to increase the acceptability of EVAs are naturally persuasive, such that the likeness of humans, the ability to gesture, and the capacity for conversation somewhat mirror the concerns of enforcement.

Trust Empowerment

A concrete definition of trust empowerment is enabling individuals to make informed decisions; it regards the delivery of data or information that humans can rely upon to make trust decisions (Marsh et al. 2020). EVAs can promote empowerment in various intuitive ways through their unique method of interaction with humans, able to draw upon state-of-the-art techniques to deliver said information. The EU's *Ethical Guidelines for Trustworthy AI* discuss the ethical imperative of explicability (2019, p.13), arguing that it is crucial for building and maintaining trust within AI systems. This imperative informs a proposed set of requirements for trustworthy AI, specifically identifying transparency and the mechanism of explainability for responsible and ethical AI. However, the development of complex black-box technologies impedes trust empowerment, a barrier to trust decisions to be made while informed. Explainability is proposed as a solution, but explanations commonly focus on informing AI experts. EVAs are suggested to bridge the gap between experts and laypeople, able to distribute knowledge in an accessible format. A recent study highlighted this approach (Weitz et al. 2019). The study compared two groups with identical information, one with purely graphical explanations and another with an additional virtual agent aid. Upon completion of the experiment, participants self-reported their trust in the system, finding a difference between the two groups with an increase in the group that experienced the virtual agent. The paper also supports the link between trust decisions and situational context, reflecting the abovementioned definitions of trust.

Is AI Fundamentally Deceptive?

A glaring issue about AI must first be addressed as a prelude to the discussion of trust enforcement for EVAs. Although this may be controversial to some, understanding the origin of AI as a method to replicate human intelligence naturally evokes the concept of deception. Under the European Union (EU)'s *Ethical Guidelines for Trustworthy AI* (2019), communication requires AI systems to inform users of their impending interaction with a machine. More explicitly, AI systems should refrain from representing themselves as humans to their end users. Although disembodied, Weizenbaum's ELIZA remains a prime example of this concern (Weizenbaum 1966), able to hold a

conversation and deceive humans into believing they are having a conversation with another human. ELIZA was noted as a "striking form of the Turing Test," which directly conflicts with the communication requirement. As a domain that prides itself in creating computers that *do the sort of things that minds do* (Boden 2016), an inherent deceptive quality is nested within its aims. The communication requirement may alleviate this concern by informing the end user, but whether this will matter as AI systems, and more explicitly EVAs, adopt the likeness, behavior, and abilities of humans remains to be determined. It is argued that the best customer experience is delivered when customers need help to tell whether they are conversing with a human or virtual agent (Hyken 2017); this does not bode confidence. It is too likely that stakeholders within the industry will be financially incentivized to develop virtual agents that are indistinguishable from their human counterparts, looking to maximize the technology's greatest value (Ammanath 2022). These examples elicit the concept of deception, which many agents, EVAs included, are often in conflict with, directly opposing the communication requirements.

Trust Enforcement

Trust enforcement overlaps with these deceptive processes, a general descriptor of methods that aim to convince, persuade, or outright force a trust decision (Marsh et al. 2020). Trust enforcement obfuscates the truth, and the many features that aim to improve the acceptability of EVAs often emulate human behavior, detracting from the available information. Substantial EVA research has focused on non-verbal characteristics, breathing patterns (Dar et al. 2019), face shapes (Ferstl and McDonnell 2018), and gestures (Kim et al. 2018), revealing how specific human features can be ascribed to agents to induce trustworthiness. These visual cues provide no discernable avenue for empowerment, undoubtedly employed by EVAs as persuasive techniques. Nevertheless, it could be perceived as unfair to ignore the benevolent aims for which these features are developed, most commonly in the name of improving the acceptance of EVAs. These persuasive techniques are by no means malicious by design. They can, however, be utilized to garner trust within risky contexts, accentuating the need for ethical consideration. As trust decisions are bound by their context, so will be the applicability of these features. Understanding the social effects induced by EVAs will undoubtedly prove to be difficult, but the discovery of these impacts is imperative considering the many unknown implications.

Concerns

Contemporary research highlights a paradox within trustworthy EVAs. Moradinezhad and Solovey (2021) discuss how EVAs have been preferred over their human counterparts or standard computer interfaces, spotlighting an unusual tradeoff between human-like behavior and trust. Their analysis reveals that agents without human behavior initially invoke more trust but that this trust is fragile and adversely impacted by failure and unreliability. On the other hand, agents who exhibit human qualities are initially perceived to be less trustworthy, but the trust endowed to these agents proves to be more resilient under failure. The authors suggest that this relationship may be due to individuals' expectations toward machines, holding EVAs to a lower standard. However, the human-like features may infer some standard of human nature, understanding that people make mistakes. This interpretation highlights enforcement's concern, including features to cloud an individual's judgment. This assertion may not be that simple. After all, enforcement is not solely about convincing but also about intent; perhaps the techniques that promote acceptability are permissible when enhanced by substantial empowerment. Of course, these considerations rely upon the context to which they are applied.

The willingness to trust various virtual agents over their human counterparts is a concern exacerbated by domains where sensitive information is disclosed. As discussed by Lloyd and Khuman (2022, p. 21–24), a variety of virtual agent-based

mental health services have increased in popularity, providing comfort for those who do not wish to utilize or have access to human-based therapy. EVAs have been similarly applied with success. Lucas et al.'s (Lucas et al. 2017) study found that virtual humans enable an increased rate of disclosure when compared to traditional therapy for military service members with PTSD. An individual's predisposition to trust EVAs with sensitive data is a cause for concern, with studies explicitly testing this relationship and highlighting a potential avenue for EVA exploitation (Lucas et al. 2014); EVAs that humans control. Again, this harks back to the communication requirement. Not only will it protect individuals from EVAs that sufficiently emulate humans to convince an individual they are, in fact, human, but it also inhibits adversaries from emulating EVAs. While these concerns extend far beyond EVAs, their human-like features only exacerbate them.

Conclusion

When discussing trust decisions, it is essential to recognize that there is no right or wrong choice (Dwyer et al. 2013); the factors that inform a trust decision are personal, situational, and often complex. To simplify these decisions, the developers of EVAs must strive for *trustworthiness*, empowering the end users in their trust decisions through transparency. Techniques that instill human features may work to cloud these decisions. This is not to suggest that such features do not provide some inherent quality that significantly benefits the end user. However, it is vital to be conscious of the outcomes, whether intended or not. Evidentially, a tradeoff exists between the affordances given to EVAs to promote acceptability and trust enforcement via deception. The EU's guidelines present an idealized view of AI, explicitly defining requirements to promote trustworthy systems. However, as much as frameworks, policies, and standards can deliver in promoting trustworthy AI, there is an even more outstanding obligation on the practitioners of EVAs to maintain these principles. Through careful adherence and consideration, practitioners should empower individuals to make their own trust decisions, accepting risk in situations they deem appropriate without the features that may otherwise convince and persuade.

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Uncanny Valley in Virtual Reality

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Synonyms

Acceptance gap; Animacy; Dehumanization; Humanness; Realism in VR

Definition

The effect of uncanny valley refers to a drop of emotional response to an artificial object. It is even higher in VR.

Introduction

Over the years computer graphics have been improved to be more and more realistic and developed special techniques to resemble various visual surface characteristics. Rendering virtual humanoid characters has been proven to be especially tricky, as humans tend to pay a lot more attention to their kind than to other beings or objects. The face is the most crucial aspect of the virtual character, as humans are extremely sensitive to deviations from a natural appearance (MacDorman et al. 2009). To create an emotional response to a virtual character, the anthropomorphism is a crucial factor. It could be assumed that the more similar a virtual character is to a human, the stronger the emotional response of familiarity.

But the effect of rising familiarity with rising realism of the virtual character changes at a certain level of similarity abruptly. At this point, the observer starts to feel alienated by the virtual character, and the emotional response becomes negative (Saygin et al. 2012). Only very high levels of realism can correct this effect again and show again an increasing familiarity (Misselhorn

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2009). Originally the Japanese robotics professor Masahiro Mori found this effect and named it in Japanese, and later it was translated to uncanny valley (Mori 1970; Mori et al. 2012).

There are several explanations for these reactions. Most of them are related to human psychology and the high sensitivity for untypical behavior of other humans. Observing others, humans are building expectations about their expressions and subconsciously compare them to typical and assumed behavior. If assumption and observations are not matching, typically an emotion of aversion is shown, as the other is assessed as socially abnormal or psychologically ill. This sensitivity against minor deviations is also active in contact with virtual characters, when they reach a certain level of realism (Angelucci et al. 2014).

One theory is linking this reaction to the subconscious mate selection mechanism, which rules out not suitable mates and creates an aversion. Another theory links it to the avoidance of pathogens, which are associated with abnormal behavior.

Another theoretical approach is suspecting the causes in the cognitive conflict that is created by the doubt if a suspect is a human or a robot. This cognitive dissonance has also been linked to an assumed threat to the uniqueness of humans, as artificial creatures are getting more and more similar. As the virtual character is known to be not alive, they might also represent a threat to human observers of being a machine themselves. Also the not living acting alive has been described as a reminder of death (Ho et al. 2008).

The uncanny valley effect is known for physical as well as virtual humanoid characters, and it has been reproduced for robots as well as for rendered characters. In virtual reality (VR), it intensifies for several reasons. The newer generations of virtual reality headsets since the first released Oculus Rift DK1 in 2012 provide an immersive experience of being at a virtual place. This virtual world is completely surrounding the user, so there is no non-virtual world visible any more (Jones 2016). Compared to screen-based media like movies, experiences, and games, the conditions of perception change in VR. While on-screens there is always an outside and an inside visible, which creates a perceivable difference in visuality, this line is not perceived any more in VR. Characters, interactions, and the surrounding world are perceived more complete and compelling. Characters are shown in real human size and three dimensional (Gosh 2017).

Users of VR tend to examine the virtual world much more intense and pay a lot of attention to the details. This higher degree of attention creates the need to make VR applications far more detailed than regular screen-based experiences. The uncanny valley effect intensifies accordingly. Even virtual characters that would be considered to be so realistic that they passed the uncanny valley and create familiar reactions again in a screen-based media are likely to be still alienating in VR. This creates a need for even higher degrees of realism in VR or making virtual characters unrealistic on purpose to avoid the effect.

Besides virtual characters, also interactions in VR that try to resemble real-world interactions have been described to have this effect (White et al. 2007).

Cross-References

- ▶ Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being
- ▶ Face Beautification in Antiage
- ▶ Player Personas and Game Choice
- ▶ Psychological Game Design

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Underground Design of Kaizo Games

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Synonyms

Game design; Game development; Indie game design; Indie game developers; Kaizo; Modding; Speedrunning; Video games

Definition

Examining the rise and design of the Kaizo subgenre of platformers, and whether it could work commercially.

Introduction

The platformer genre has been tried and tested for more than 30 years across multiple platforms, and while there have been many platformers released in the commercial market, there is a subset that remained hidden for a long time. Kaizo design takes platforming to the absolute highest of skill and has spawned a whole culture and development that has only grown in popularity.

What Is Kaizo

Kaizo's meaning in Japanese is defined as "reorganize, restructure, or reconstruct," but it has become the definition for the subgenre of platforming. Kaizo games are about incredibly difficult level designs; far beyond what would be in a commercial game.

The first example, at least reaching popular culture, would be *Kaizo Mario World* in 2007 (https://en.wikipedia.org/wiki/Kaizo_Mario_World). At the time, people described it as the hardest platformer ever made. The game was built off *Super Mario World*, and that detail is a major factor limiting the reach of Kaizo games that will be elaborated on in a minute. Nothing was added to Kaizo Mario World in terms of new assets, but the game used what was in the original release to design original levels.

That same year also had what would become the first original Kaizo game in the form of the *I Wanna Be the Guy* (https://kayin.itch.io/iwbtg) series.

I Wanna Be the Guy

I Wanna Be the Guy: The Movie: The Game like Super Kaizo World was the first time where these kinds of games broke into the mainstream. IWBTG was an entirely original design but used assets from other games for enemies, music, and obstacles.

Players had to go through challenging platforming levels where they could be killed at any time and sent back to the nearest checkpoint. The game embraced a kind of obstacle that has been dubbed a "Kaizo trap." Kaizo traps are obstacles hidden that the player would have no way of knowing about until it was too late, killing them and forcing the player to repeat the entire section

again. The only way to know where a Kaizo trap is located is to spring it.

The game had one official sequel with *I Wanna Be the Guy Gaiden* before the creator stepped away. Since then, modders and fans have been creating spinoffs of their very own, and there are too many to list here. What separates Kaizo games from the IWBTG titles is how they are developed.

Building a Kaizo Game

Kaizo games are technically illegal to play (https://www.nintendo.com/corp/legal.jsp#download_rom) and make because they are built off the ROM files of Mario games. ROM stands for "read only memory" and for the purposes in this entry represents the data that contains everything about the game. Of the Mario games, Super Mario World is now the most widely used as a foundation for Kaizo games, and there is a site that archives all the hacks made for it.

Since owning and/or manipulating someone else's ROM files is illegal, the author cannot provide exact names of programs or sites that host these files. Modders today have a dedicated "Mario World editor" program that they can use to create original levels and assets within the Super Mario World engine. For people who are used to Super Mario Maker, this other program is far more robust and allows modders to create elements that were never in the original game. This can go as far as having original music, mechanics, and new game systems.

Two of the most popular Kaizo hacks released in 2018 were "Invictus" and "Grand Poo World 2," both featuring original level designs and elements.

Once someone has finished their Kaizo game, they need to use one final program that allows them to create a "patched" version of the original ROM: replacing the respective files in the game with the modified ones. After that is done, the file can be run on emulators and could even be installed on a custom cartridge to be playable on the original platform.

Why Super Mario World

The most popular Kaizo hacks on the market are all built off the design and engine of the classic Mario games, with Super Mario World being the most popular now. The reason why Super Mario World has been the basis for so many hacks goes beyond just the name recognition.

From a design standpoint, the game is one of the best platformers of the classic era. It was one of the few titles to have two dedicated jump commands: Mario's normal jump and his "spin jump." Having two kinds of jumps added variety to the platforming and gave modders more ways of designing obstacles. As an example, modern Kaizo hacks have been allowing players to switch Mario's jump in mid-jump – requiring additional technical play.

Modders have thoroughly examined the engine of the game to discover bugs, advanced mechanics, and create elements that Nintendo would have never thought of. This also extends to the items, with designers creating new items for their Kaizo hacks or finding new ways of using the preexisting ones. The Kaizo hack "Fly me to the Stars" showcased and tested Mario's cape mechanics and physics beyond what Nintendo did.

The canvas of Super Mario World has been the main reason for its longevity in the Kaizo community.

Kaizo Design

Kaizo design is all about challenging the player's mastery of not only the original game, but to be prepared for anything. The first element of a Kaizo game is the difficulty – even Kaizo games that are rated as "easy" are still harder than any commercially released game.

Level design is meant to push the player to the highest levels of skill to get through them. Depending on the game in question, a Kaizo level can either be one demanding series of obstacles or be split into several sections.

A section is a collection of obstacles and hazards the player must get through before they reach a checkpoint that saves their progress. A Kaizo

section is built to be one continuous set of actions on the player's part; failure at any point will send the player back to the beginning of the section.

The hardest Kaizo levels will require pixel-precise play by the player to get through them. Taking things further, specific glitches (bugs that do not cause the game to crash) may be required by the player.

Two infamous obstacles featured in Kaizo games are "Kaizo blocks" and "Kaizo traps." A Kaizo block is an invisible block set purposely in what would be the easiest path to get through a section while making a jump. There is no way of knowing where a Kaizo block is until the player hits it and most likely dies. To avoid it, the player must purposely jump at an off angle that clears the block while still making the jump.

A Kaizo trap is setting up something to attack the player from either on or off screen with no warning. Usually, these traps are set up at the end of a difficult section as one final trick to catch the player. As with a Kaizo block, there is no way of knowing where a Kaizo trap is until it goes off – either killing the player or they avoid it. In Super Mario World hacks, many designers set up Kaizo traps just before the goalpost once the player thinks they are safe.

Kaizo design is explicitly set up around having one best way through the map. Unlike 3D design, you are not designing a Kaizo level around multiple solutions or paths. These levels not only test the technical skills of the player, but their ability to perform a precise set of actions from start to finish. Therefore, watching someone beat a Kaizo game looks very easy because they have done it enough times to build up the muscle memory and memorize the entire stage. There is no randomization in a Kaizo level: the same solution should work every time like clockwork.

This is achieved by using local timers. Each section of the level operates on its own cycle of animations and actions. Through this process, it allows the designer to know exactly what every element in the level is doing at any given time.

The mechanical nature of a Kaizo game also makes it the perfect candidate to watch Tool-Assisted-Speedruns or TAS (https://en.wikipedia.org/wiki/Tool-assisted_speedrun). A TAS is when an AI is programmed to play a game at a level of precision far beyond the abilities of a human player. These runs will often make use of frame perfect tricks and glitches that can only be performed by the computer.

The original Kaizo games following Kaizo Mario World did not make any quality of life updates to the game. That meant players could only save their games after a ghost house or boss, and they were limited on lives. As the community grew and Kaizo games became more popular, there has been a push to add more features to Kaizo games to make them less frustrating (but still difficult) to play.

Kaizo hacks today now give players infinite lives – removing any threat of game-overs – saving at any time on the world map, instant retries when they die, among other updates. Kaizo has grown thanks to modders learning from other games to incorporate new challenges or features into their designs.

From a cultural standpoint, more consumers have been exposed to it thanks to the rise of the Mario Maker and Speedrunner communities such as Awesome Games Done Quick (https://www.youtube.com/watch?v=GY0HnqnYMO8). With that said, the design of Kaizo does call into question whether it could work in a commercially released game.

Is Kaizo Marketable

Designing a Kaizo game is not the same as designing a game with the intent of selling. All the Kaizo hacks that are available would never be approved for sale at any digital store due to the as-for-mentioned modifying of a company's files. On one hand, that does leave room in the market for someone to try and make a commercial Kaizo game, but there are some issues there.

First, any game that tries to have a price tag will be immediately competing with the incalculable number of free Kaizo titles. The design would need to do something grander to justify the cost and stand out from those games. It would be easy to assume that just being a legal Kaizo game would be enough, but that is not the case here.

The major point about Kaizo design is how laser-focused it is in terms of the intended audience. There are three kinds of people interested in Kaizo games: players skilled enough to play them, modders who design them, and the audience who watches these games being played.

The first two groups often overlap, with high profile Kaizo players oftentimes designing Kaizo hacks as was the case with both Grand Poo World 2 and Invictus. Trying to convince them to buy a Kaizo game is going to be a tough sell, as they can just create their own or wait for their friends to design a new one. The sheer difficulty of playing a Kaizo game is why there are more people who watch runs as opposed to playing them, leaving them out of the potential consumer base for a Kaizo title.

There is the idea of making a "casual Kaizo" experience, but you once again run into problems with the market. As surprising as it sounds, there are Kaizo hacks designed for first timers to the genre. If someone is going to try and learn a Kaizo game, they will most likely go with the popular examples.

The hardest commercially released 2D platformer in 2018 was Celeste. The game's difficulty escalated over the course of three difficulty settings (two were hidden at the start of playing). The final difficulty required absolute precision on the player's part – reaching levels of Kaizo design. With that said, the developers implemented an assist mode to make sure anyone could finish the game (http://gameaccessibilityguidelines.com/celeste-assist-mode). Despite the difficulty of Celeste, the game was not marketed towards Kaizo players.

It is easy to assume that just because modders have used Super Mario World for so long that there's room to compete. However, from a design standpoint, trying to build a brand-new game with the explicit purpose to compete with the free Kaizo hacks would have the designer not only being compared to them but also indirectly competing with Super Mario World's design.

The power and scope of the tools being used has given modders complete freedom in designing levels and games. Another subgenre of the Kaizo community are "puzzle levels" – stages that take place in a single screen and require the player to figure out a specific solution.

Learning Kaizo

The best, and legal, way to examine and experience Kaizo design would be via Super Mario Maker 2 for the Nintendo Switch. Just like the first game, many Kaizo creators and players have taken to the game as the means of building levels and playing them.

While Super Mario Maker 2 lacks the functionality and depth of the created Kaizo tools, it is easier to learn and there are no worries of legal repercussions. Not only that, but the tool is the only way to make levels using the styles of Super Mario 3D World and New Super Mario Bros. The easiest way to find Kaizo-styled levels, for the most part, is to search for the hardest levels with the lowest completion by players.

For studying Kaizo games without having to play them, just searching for "Kaizo Speedruns" on YouTube should provide more than enough footage of popular streamers who have perfected these games.

Conclusion

The appeal and reach of Kaizo design and the community around it has crossed over to the mainstream. Even though it would be hard to compete directly with free Kaizo games, it does not exclude developers wanting to make commercial platformers on the harder side as evident by Celeste.

Given the growth of the community, the author expects to see further evolutions from Kaizo creators in the coming years. The only question that remains is if IP holders such as Nintendo will continue to allow them to exist underground, go after creators for infringing on their rights, or even allow them on the platform.

From a gameplay standpoint, Kaizo games represent the height of precision platforming design and are great at studying to see the

extremes of difficulty design, and the work that goes into playing them.

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Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement

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Synonyms

Underwater image enhancement; Underwater image restoration

Definition

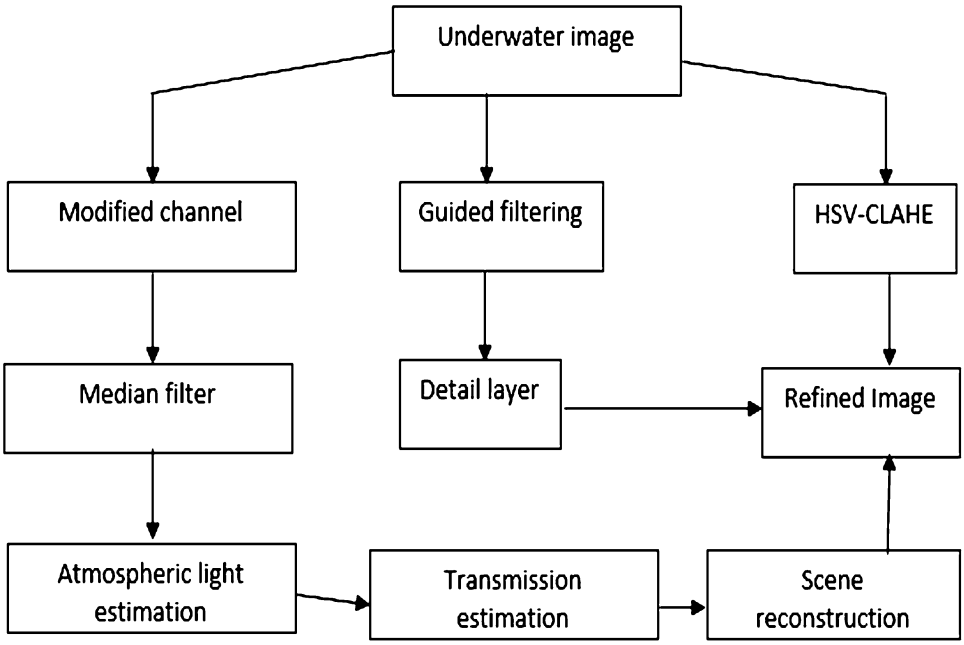
Underwater image enhancement is a process to improve the underwater image quality for further applications in several ways such as to recover image visibility, preserve details, reduce image noises, and improve contrast and color balance.

Introduction

Underwater images are often distorted due to two main reasons such as the light absorption and scattering. Water tends to absorb the red light (longest wavelength) compared to blue and green lights. Thus, the underwater images will become bluish or greenish appearance. Underwater images also suffered in limited range visibility, low contrast, and blurring due to the light scattering effects. Therefore, underwater image enhancement is needed to be carried to improve the underwater image quality, enhance image contrast, and restore the image visibility.

State-of-the-Art Work

The early attempt in recovering underwater image visibility was the polarization analysis method (Schechner and Karpel 2005) which can increase the image visibility range, improve the image contrast, and correct the image color. The dark channel prior (DCP) (He et al. 2009) was originally proposed to remove the light scattering effects on the haze image. Due to the promising results gained by the DCP method, DCP had been integrated with the unsupervised color correction method (Iqbal et al. 2010) in order to enhance the degraded underwater image and color contrast (Yang et al. 2011). Later, an underwater DCP method (Wen et al. 2013) had been introduced along with an underwater optical model to take account of the light absorbing effect of water. Besides that, Lu et al. (2013) had replaced the soft matting in DCP scheme with guided trigonometric bilateral filter (GTBF) to reduce the computational time and improve the image contrast using an automatic color equalization-based enhancement method. Besides that, another attempt in the underwater image enhancement was to carry out color correction on the red channel based on the Gray-World assumption and applied the DCP dehazing method on the blue-green channels (Li et al. 2016). As compared with histogram equalization, DCP method showed a better performance in improving the quality of underwater image (Sahtya et al. 2015). Red channel prior method (Borkar and Bonde 2016) applied the DCP on red channel only due to the reason that red channel usually go through maximum attenuation. A modified DCP method (Yao and Xiang 2018) was proposed to obtain attenuations of RGB channels separately and applied color correction for degraded underwater image.



Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement, Fig. 1 UEDD method

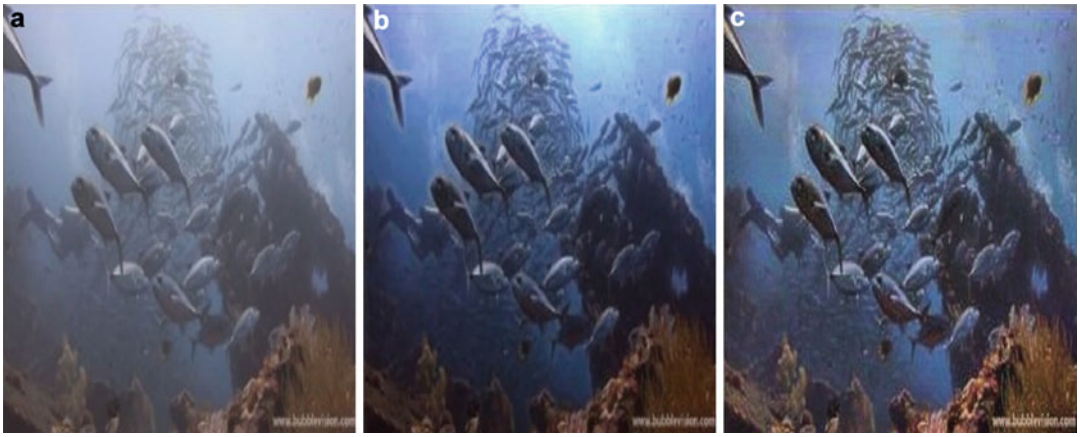
Some contrast enhancement methods such as contrast-limited adaptive histogram equalization (CLAHE) had been proposed for the underwater image enhancement. For instance, the Mixture CLAHE (Mix-CLAHE) (Hitam et al. 2013) enhances the underwater image visibility by combining the RGB-CLAHE and HSV-CLAHE. In addition, a comparative analysis (Wong et al. 2014) had proved the effectiveness of RGB-CLAHE and HSV-CLAHE in enhancing underwater image quality as compared with the contrast stretching and histogram equalization (HE). In addition, another underwater image enhancement had been proposed by fusing the CLAHE and unsharp mask (USM) (Zheng et al. 2016) to improve the underwater image quality.

Underwater Enhanced Detail and Dehaze Technique (UEDD)

Modified channel prior stated most images will contain many bright pixels and dark pixels, whereas the dark pixel and bright pixel indicate the pixels with lowest intensity and highest intensity respectively. Figure 1 showed the flow of the UEDD method. The algorithm of UEDD method is showed as follows:

The input image I^c will be a degraded RGB underwater image where c represents the RGB color channels. The UEDD method will compute the modified channels based on the modified channel prior and filtered by median filter as Eq. (1). The atmospheric light A is selected as the brightest pixel among the modified channels. After that, the UEDD method computes the transmission t as Eq. (2) where ω is a constant used to control the amount of descattering effect. The underwater image formation model is defined as Eq. (3) where J is the reconstructed underwater image. The image will then be reconstructed as Eq. (4) where t_0 indicates the lower boundary of the transmission.

$$\text{median}\left(\frac{\left(\min_c\left(I^c\right)+\max_c\left(I^c\right)\right)}{2}\right) \quad (1)$$



Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement, Fig. 2 Image 1 (**a**) Input (**b**) DCP (**c**) UEDD method

$$t = 1 - \omega \left(\frac{\text{median}\left(\frac{\left(\min_c (I^c) + \max_c (I^c) \right)}{2} \right)}{A} \right) \quad (2)$$

$$J = It + A(1 - t) \quad (3)$$

$$J = \frac{I - A}{\max(t, t_0)} + A \quad (4)$$

Meanwhile, the UEDD method computes the detail layer I_d as Eq. (5) as the digital image can be decomposed into the base layer and detail layer. The base layer I_s is the smoothed image of input underwater image that is produced by the guided image filtering. In the meantime, the HSV-CLAHE will be applied to the input degraded underwater image in order to enhance the color contrast. The UEDD method will then produce a refined underwater image I_f as Eq. (6) by combining the detail layer, reconstructed scene, J and HSV-CLAHE image I_{hsv} that is the input image after applied HSV-CLAHE and n is the scale of the detail layer.

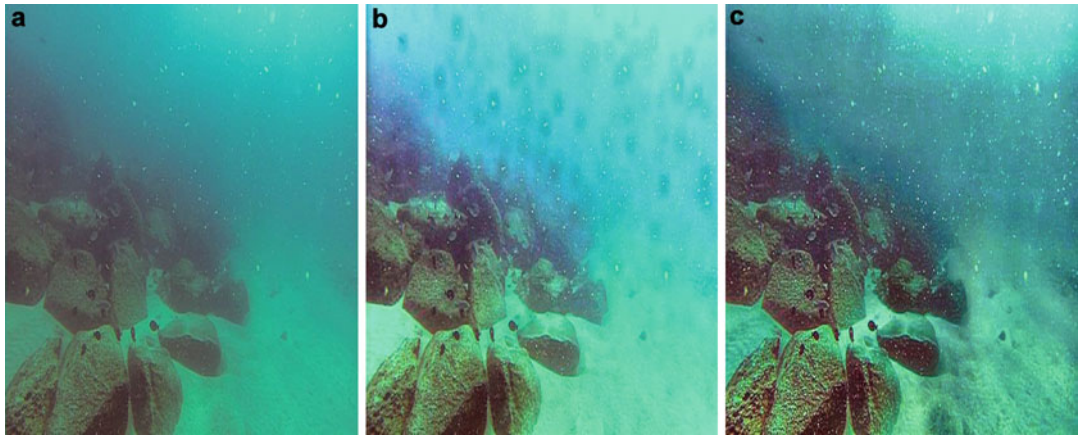
$$I_d = I - I_s \quad (5)$$

$$I_f = \frac{J + I_{hsv}}{2} + nI_d \quad (6)$$

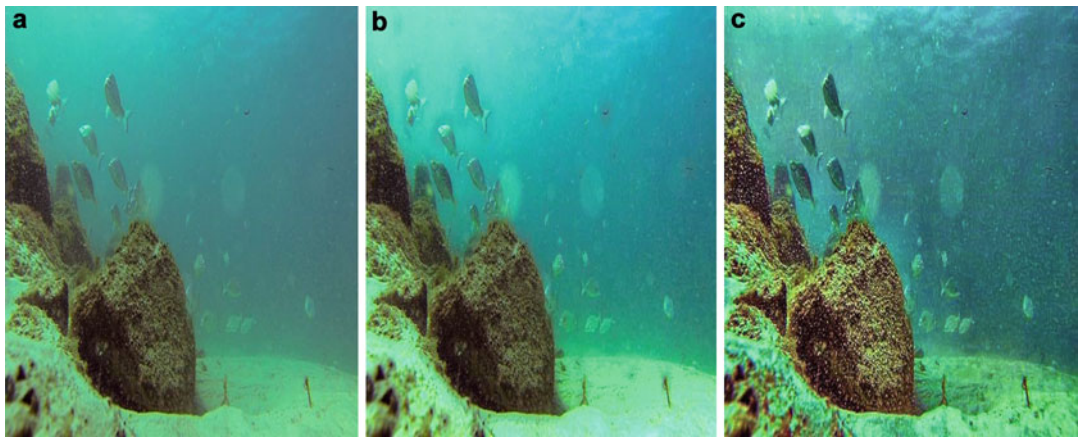
Figure 2 showed the result of image 1. From Fig. 2, UEDD method and DCP method can enhance the underwater image quality in terms of removing haze effects. However, the image recovered by DCP method was found to be darker than that of UEDD method. In terms of image details, the UEDD method also preserves more image details than the DCP method. From the recovered image of the UEDD method, the object edge is much clearer to be seen. The UEDD performed about 44.67% better than DCP in terms of the accuracy of recovered image contrast based on MSE test.

For sample image 2, the recovered image of the UEDD method can also see the object edge clearer as compared to the DCP method. Unlike the DCP method which produced an over-saturated image, UEDD method had produced a clear image that is natural looking. Figure 3 showed the results of DCP and UEDD on image 2. Based on the MSE test, UEDD had recovered the image contrast about 216.12% more accurate than the DCP.

From Fig. 4, UEDD method had improved the visibility of image 3 and recovered more image details. However, the images recovered by UEDD method for images 2 and 3 still have a



Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement, Fig. 3 Sample 2 (**a**) Original (**b**) DCP (**c**) UEDD method

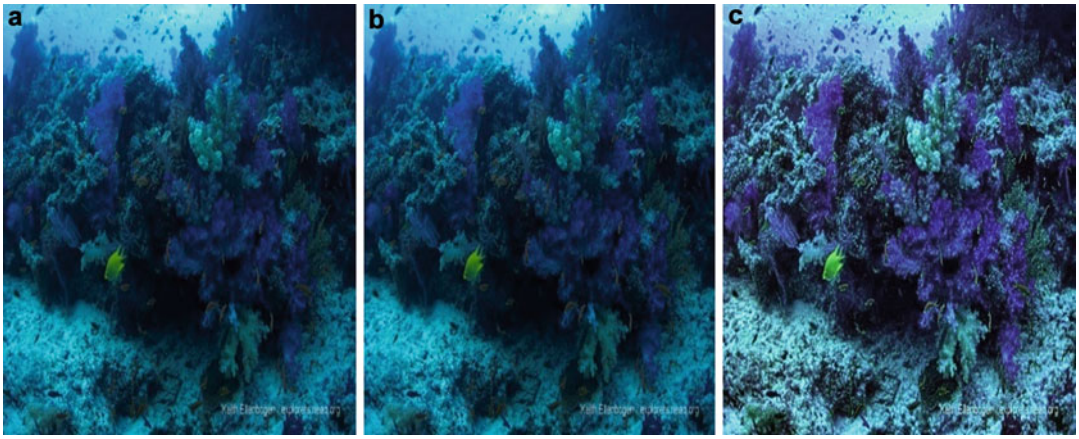


Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement, Fig. 4 Sample 3 (**a**) Original (**b**) DCP (**c**) UEDD method

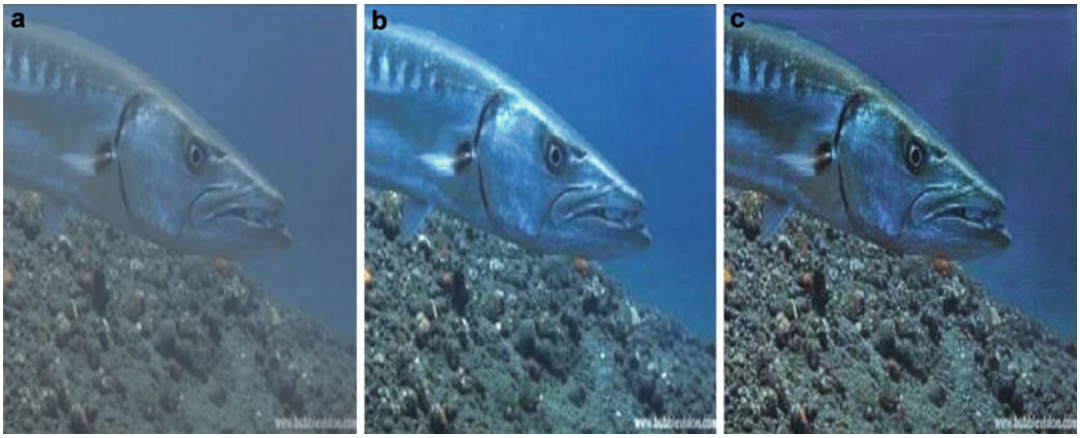
greenish appearance. This indicates the color correction need to be considered in the study. Figure 4 showed the results of DCP and UEDD on image 3.

The result for image 4 obtained by UEDD method had showed the ability to enhance the image details where we can observe the small fishes that are almost hidden in the image due to the similar color. However, the UEDD method cannot remove the bluish appearance. Figure 5 shows the results of DCP and UEDD on image 4. Based on MSE test, the image contrast recovered by UEDD is less accurate about 99.98% due to the high amount of image details.

Figure 6 shows the results of DCP and UEDD on image 5. From the Fig. 6, UEDD and DCP clearly managed to remove the haze effects. The level of detail obtained by UEDD method is higher and the image contrast recovered is about 9.9% less accurate as compared to DCP. Besides that, the recovered image of UEDD method looks more natural as compared with DCP method.



Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement, Fig. 5 Sample 4 (**a**) Original (**b**) DCP (**c**) UEDD method



Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement, Fig. 6 Sample 5 (**a**) Original (**b**) DCP (**c**) UEDD method

Mean Square Error (MSE) Test

The MSE test is a common test used to evaluate the accuracy of the recovered image contrast. The lower the MSE value obtained, the recovered image contrast is more accurate. Based on the MSE test, UEDD shows the image contrast recovered by the UEDD has more accuracy as the MSE value is averagely lower than the DCP method. UEDD computes higher MSE value due to the too many image details contained in sample image 4.

MSE test			
	DCP	UEDD	Percentage(%)
1	1427.63	986.819	−44.67
2	1691.87	535.199	−216.12
3	586.552	570.188	−2.87
4	0.207328	1681.18	99.98
5	610.971	678.139	9.9

Conclusion

In a nutshell, underwater enhanced detail and dehaze technique (UEDD) can improve the image quality in terms of visibility, removing haze effects, and preserving the image detail.

Cross-References

- ▶ Computer Games and Artificial Intelligence
- ▶ Computer Go
- ▶ Constructing Game Agents Through Simulated Evolution
- ▶ Game Player Modeling
- ▶ Machine Learning for Computer Games
- ▶ Meta Artificial Intelligence and Artificial Intelligence Director
- ▶ Monte-Carlo Tree Search
- ▶ Multivariate Visualization Using Scatterplots
- ▶ Overview of Artificial Intelligence
- ▶ RTS AI Problems and Techniques
- ▶ Scalable Techniques to Visualize Spatiotemporal Data
- ▶ Skull and Roses Card Game
- ▶ StarCraft Bots and Competitions
- ▶ Tensor Field Visualization

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Underwater Image Enhancement

▶ Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement

Underwater Image Restoration

▶ Underwater Enhanced Detail and Dehaze Technique (UEDD) for Underwater Image Enhancement

Unified Modeling Language (UML)

▶ Unified Modeling Language (UML) for Sight Loss

Unified Modeling Language (UML) for Sight Loss

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Synonyms

Accessibility; Block-based programming; Braille; Diagram; Educational game; Sight loss; Software system; Unified Modeling Language (UML)

Definition

Software systems are digital products of development whose purposes vary.

Generally speaking, a problem is presented and a solution is proposed with programming and other techniques and practices. A modeling language is an, often graphical, way of describing the conceptual constructs of a software system. It shows the complexity and concepts of a system, similar to the functions of a blueprint. One such example is the Unified Modeling Language (UML) which is a modeling language used in software engineering that allows stakeholders to conceptualize and visualize a software system before, during, and after its development. UML uses diagrams, which are visual representations of anything that requires or could benefit from a visual representation. An example of a UML diagram is a class diagram. Class diagrams include what classes will exist in a software project, what member attributes and member functions each class will have, and how each class interacts with the other. These interactions can be function calls, inheritance, and implementation if a class extends an interface. Often software systems may need to consider accessibility, which is a set of rules and practices that target people with disabilities by enabling their participation in a given activity by easing their access to facilities, information, etc., and is often enforced by law in many countries. One such occasion that may require accessibility is sight loss. Sight loss can be from birth, developed, or accidental. It may affect visual acuity, the field of view, or both. Some cases require corrective devices, such as glasses, surgical intervention, or both. However, some cases may not be able to be treated. Some people with sight loss may use a method of reading and writing called Braille. Braille facilitates people with sight loss to communicate in writing. This brings people with sight loss closer to society; however, only a small percentage of people with sight loss know Braille. Educational games, or serious games, are games that are designed to teach a topic or skill. Their primary goal is to teach and they use gamification to do so. Blockbased programming is a form of programming language that uses small chunks of interactable code to connect together to create a program.

Introduction

With the popularity of the Unified Modeling Language (UML) in both industry and academia, it is important to remember that it is not designed for users of all abilities. Since UML is a visual modeling language, it proves to be difficult for people with sight loss to read and write. This entry describes Braille, a system of writing for people with sight loss. Additionally, it describes what UML is and how it works. Finally, it describes some applications of UML for people with sight loss.

Braille

Born in the early nineteenth century, Louis Braille was the creator of the writing and reading system that takes after his name. After a tragic accident at an early age, he lost sight in one eye. It is thought that after a couple of years, the other eye developed sympathetic ophthalmia, also losing its sight. His family, in which all members could write and read – an uncommon feat for the time – decided to send him to another city so he could study at a school for blind people. There, he started having contact with books for the blind which were written with the Roman alphabet letters in relief. This writing system was complex and ineffective due to the complexity of how Roman letters were fashioned. A new means of written communication was needed.

When the French revolution broke out, Charles Barbier de la Serre, a sighted military person, developed a writing system that was meant for secrecy and reading in poor lighting conditions. Barbier came up with a phonetic alphabet written as dots in relief on a paper. This idea was presented to the Institute for Blind Youth, where Louis Braille had his first contact with the proposed method. Despite being proven to be a better way for blind people to achieve written communication, Barbier was a sighted person and therefore could not understand the particularities and needs of those not sighted. Based on Barbier's proposal, Braille came up with the writing system used today and helps integrate people with sight loss into society (Jimenez et al. 2009).

Reports and surveys indicate that, in Canada, 1.5 million people identify as having sight loss, and more than 5.5 million have a condition that may lead to sight loss in the future (CNIB Foundation, retrieved on March 30, 2022). On the other hand, only a small percentage of this population knows how to read and write in Braille (Creedy et al. 2018).

Software Design and Software Design Practices

Designing software is a difficult task, especially when designing reusable software. Software designers and developers find this task easier because they have had previous experiences that allow them to foresee how they can break down objects into classes with precise granularity. Part of this experience is evidenced by the ability to recall what these professionals have done before, and apply that knowledge to the current project they are working on (Gamma et al. 1995).

Examples of design patterns include singleton, adapter, observer, and factory method patterns. Each of these has its own purpose in the software system. The singleton pattern, for instance, is often used when there is a need to have only one instance of a class alive in the system.

Software design patterns and modeling come together when the software product to be developed needs to be designed prior to its development. By understanding how to use these patterns, the software can be designed with diagrams that represent what and how the code should be written.

Unified Modeling Language (UML)

The Unified Modeling Language, or UML, was first adopted in 1997. It is a general purpose visual modeling language that is used to design, visualize, construct, document, and specify software systems; however, it is not a programming language (Rumbaugh et al. 1999). It is intended to be used at all levels of development and with all development methods. Although UML does not define its own standard practice, it is intended to be used in an iterative development process (Rumbaugh et al. 1999). UML is often used in many agile and scrum-based development environments.

UML is made up of several types of diagrams displaying various aspects of a software system. It was designed and grouped into several concept

areas. These areas include static structure, dynamic behavior, implementation constructs, model organization, and extensibility mechanisms (Rumbaugh et al. 1999). These concepts were used in the design of the language, as well as in how the models are built.

As previously mentioned, the Unified Modeling Language comprises many different views, including the static view, use case view, state machine view, activity view, interaction view, and model management view (Rumbaugh et al. 1999). These views are made up of diagrams that rely on visual aspects and symbols to better represent the aspects in the diagram. Some of the popular diagrams include use case diagrams, activity diagrams, and sequence diagrams. Each diagram works together to provide an overall view of the program, both with how the system should act and how users interact with it.

This system continues to be popular both in industry and within programming courses. It is considered a useful language to help design, implement, and understand specific software systems.

UML for People with Sight Loss

Representing UML diagrams for individuals with Sight Loss is a difficult challenge since UML diagrams are presented visually. This can be hard for Sight Loss programmers to understand the complexity of the software system as there are not many applications to portray the graphs to these individuals. UML is an advanced software design technique that may be challenging for visually impaired users when they transition from programming to understanding UML diagrams. While there are accessibility options in programs like Microsoft Visio for blind programmers, this can be challenging for a student that is trying to learn the concept as they are not sure how different software design concepts can come together in the diagram. This is important as it will severely limit blind programmers as they try to improve their skills and join the job market (Coburn and Owen 2014).

Researchers have developed UML tools for blind programmers so they can relay relationships between classes and state elements. In the first iteration created by Coburn and Owen (2014), they represented elements using combinations of push-pins, rubber bands, and sticky notes that included class details in Braille. The rubber bands were used to connect elements so they could be felt and followed by the user with their sense of touch. Specific relationships (i.e., nesting and generalization) can be created by a push-pin that shapes each element's relationships. While this approach was appropriate for the short term, the authors quickly discovered that there must be an application that can quickly interpret and create diagrams.

Audio Browser is the successor to Coburn and Owen's (2014) previous solution to allow blind programmers to develop UML diagrams. This application can interpret and present different diagrams by saying distinct names, attributes, operations, and associations using a computer voice-over that reads attributes to the user. Audio Browser allows the user to navigate the diagram using the up and down arrow key and read a set of frequent items called a tab group. The arrow key also allows the user to go to a list that may include nested classes, classes that the current class inherits, and classes that inherit the current class. An example of the application reading to the user is if the attribute is x: int = 0, it will be spoken as "x colon int initial zero." If there was any ambiguity/clarification needed for the user, the user can navigate the letter with the right and left arrow keys. For the blind programmer to understand the physical structure of the diagram, the program will read the placement of the class based on a certain spatial placement and pitch. For example, if the class was placed in the bottom left of the application, the user will hear it at a low pitch and on the left ear.

Educational Games

Educational games, also known as serious games, are educational tools that combine the aspects of

game play with a learning outcome of a topic. Alvarez and Djaouti suggest that educational games should include three important criteria: gameplay (the type of playful structure), purpose (the functions beyond the game aspect), and sector (the areas of applications covered) (Alvarez and Djaouti 2011). These games are often used in learning environments, such as classrooms, where they are used to improve learning experiences and can be used to create a laboratory-like environment that can help with increasing engagement and imagination (Abt 1987).

Within the domain of software engineering and computer science, these games are often completely digital and work to teach a wide variety of concepts, from computational thinking to parallel programming. Additionally, there are games developed for a wide variety of skill levels, ranging from primary school aged children to university classrooms.

Often times, these educational games use a concept called block-based programming to run the coding portions of games, especially for younger users. Blockbased programming uses a more puzzle-based approach, using a series of blocks that fit together to create a runnable program. Each block in a block-based programming language can be anywhere from a single variable to several lines of code, often condensing the program and reducing the amount a typing user may have to do. It uses a more visual approach to show the user where and how the blocks fit together and overall acts as a way to prevent syntax errors that are so common with novice programmers (Weintrop 2019).

With computer science education becoming so prevalent, there has been an increase in recent years in the number of computer science educational games that use block-based programming. Games such as Code.org and Blockly have become more common. Code.org uses block-based programming to encourage students in learning how to code. It uses puzzles involving pop culture characters, such as Frozen and Star Wars, to help increase the engagement (Code.org n.d.). The Blockly games are created by Google. Blockly uses its own version of a block-based programming to create a series of different games designed to encourage development. Blockly is designed to be open source to allow for changes to be made (Blockly Games n.d.).

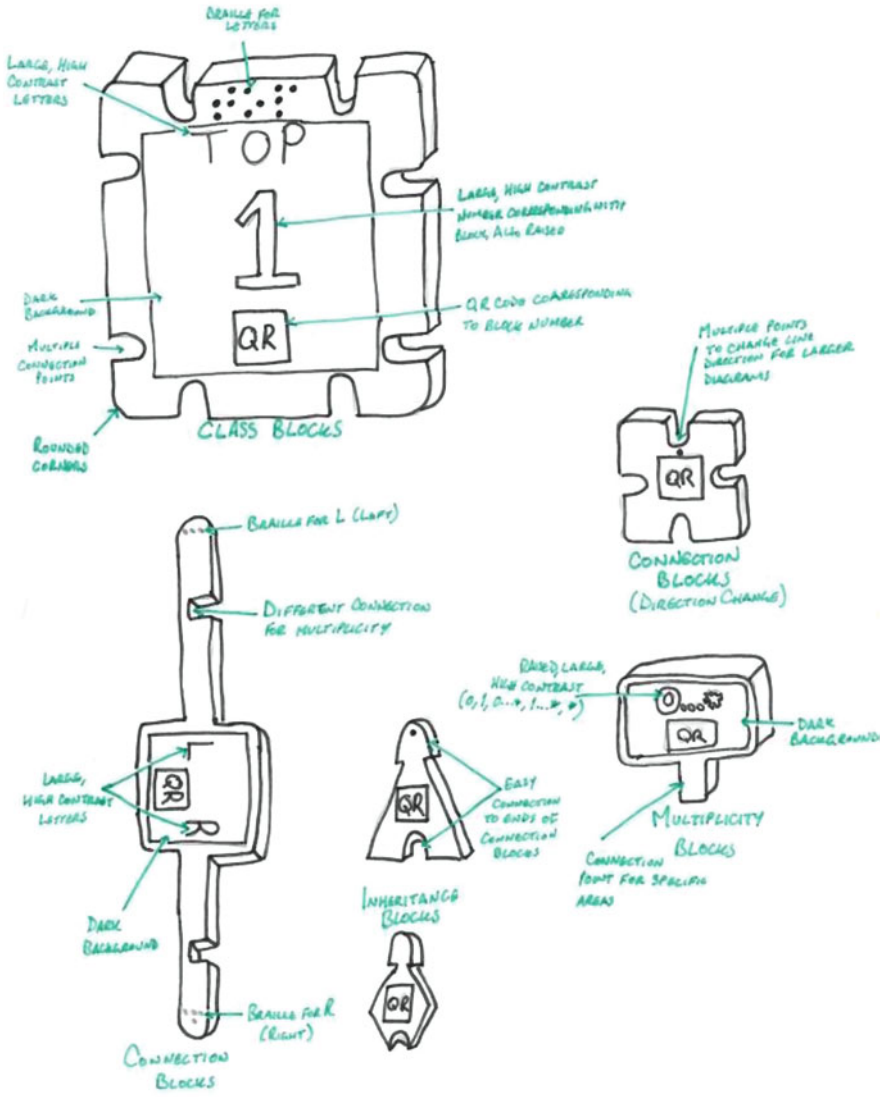
Although only two educational games were specifically mentioned, there are a wide variety developed and under development by both industry and researchers.

Creating UML Blocks for Sight Loss

One way to bridge the gap between UML and accessibility for people with sight loss is to create a series of physical blocks to represent the UML class diagrams. We have been working to develop a set of UML class diagram blocks, as seen in Fig. 1. This set will include several 3D printed blocks, including class blocks, connection blocks, inheritance blocks, multiplicity blocks, and more. The blocks are designed to include high-contrast identifiers, using white lettering on a dark blue background, and all of the letters and numbers are raised, to allow the user to feel the words. Similarly, the blocks include Braille labeling for those who can read Braille.

Each block uses shapes similar to the diagram. The class blocks are in a square shape to represent the class blocks in the diagram. Each of the class blocks has a different number to help the user to distinguish between each of the blocks when they build the diagram. Each of these numbers is raised. There are also Braille and English letters showing where the top of the block is, to help with organization. Finally, each of the class blocks includes 8 rounded-edge connection points, to allow for multiple connections between them. It also allows for as much flexibility as possible.

The connection blocks have 2 main pieces: a line connection block and a block to allow a change in direction. These blocks show how each block is connected and have multiple ways in which the lines can connect. The line connection block provides rounded edges that fit into the class blocks and the blocks that allow a change in direction. They can also fit into the inheritance blocks. The line connection block also includes a square connection point to allow the user to insert



Unified Modeling Language (UML) for Sight Loss, Fig. 1 A detailed design blueprint for the UML blocks

multiplicity. The connection points are designed to be different, allowing the user to feel the specific blocks that can be inserted into the corresponding slot.

There are two different blocks to show inheritance: an arrow and a diamond. The arrow is used to show inheritance, while the diamond is used to show aggregation, similarly to how they are used in the UML diagrams. These blocks also use rounded edges, allowing them to connect to the end of a connection block and fit into the class blocks. The inheritance blocks include a raised dot on the upper side to allow a user to feel which side should be facing upward.

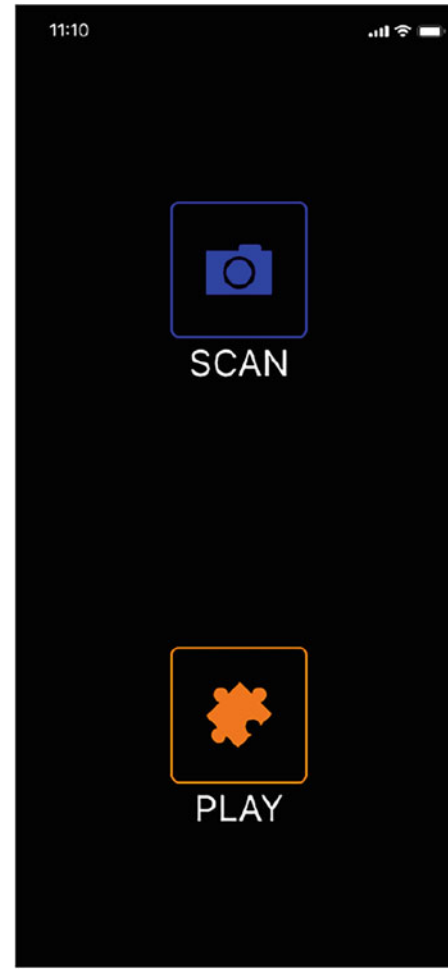
Finally, there are multiplicity blocks. These blocks include multiple types of multiplicity, such as zero-to-many, one-to-many, and more. These blocks use the square connection point and can be inserted on either end of the line connection points. The multiplicity shown on the

Unified Modeling Language (UML) for Sight Loss, Fig. 2 A paper prototype of the UML block diagram that will be placed on the 3d printed blocks

block is raised to allow someone to feel the letters and symbols.

Each block includes a QR code for easy access to the app. The QR code was chosen over computer vision to decrease the computational resources needed for computer vision. It was also chosen because, as long as the QR code is intact, the blocks can be cut out or slightly blurry in the pictures. Examples of paper prototypes of these blocks can be found in Fig. 2.

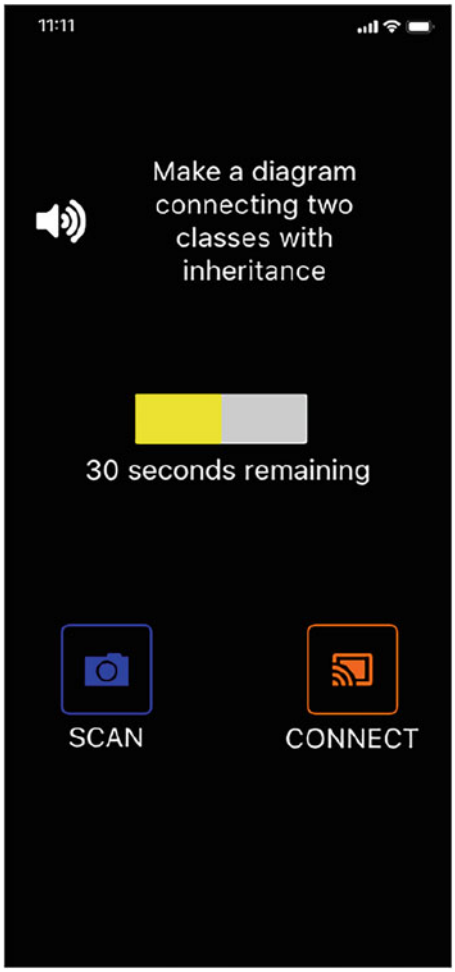
Once a UML class diagram is created using the blocks, the user will be able to take a picture using a mobile app. This app will include text-to-speech capabilities, as well as large, high-contrast buttons. The app will include only two buttons, as seen in Fig. 3. The first button allows the user to take a picture of the blocks. Once the picture has been taken, the app will decode the QR codes and provide audio and haptic feedback for each QR code that it finds. After hearing how many QR codes were found in the picture, the user will have the option to retake the photo, if it is missing QR codes, or send the QR codes to a computer application.



Unified Modeling Language (UML) for Sight Loss, Fig. 3 A mockup of the main screen of app

The computer application receives the QR code information from the mobile app and will use that information to create a visual representation of the graph. From here, the user will be able to use speech-to-text or keyboard input to fill out the information in each class. The user will also be able to hear what the graph looks like through a series of tones and text-to-speech.

However, if a novice to software design and UML wants to use the application to practice developing UML class diagrams, there will be an option to complete a series off challenges in the form of an educational game. The purpose of this game would be to help the user practice developing UML diagrams. This game would be



Unified Modeling Language (UML) for Sight Loss, Fig. 4 A mockup of the educational game portion of the app

developed to allow equal access for sighted people and people with sight loss.

To begin, the user would select the Play button, as seen in Fig. 3. This would take the user to the screen in Fig. 4. The game would include a series of sample questions, such as "Make a diagram that connects two classes using inheritance." This question would be read aloud, and the user would have the option to hear the question again using the large speaker button beside a written version of the question. The user would then be given a set amount of time to complete the challenge, which would be given visually in both a large progress bar and the exact time remaining in large print. Additionally, audio cues would be given for those with sight loss. Using spatial placement, a soft beeping would accompany the timer, showing where the progress is along the bar, with special reminders at half time and the thirty-second mark. When the user completes their UML diagram using the UML diagram blocks, they would press the Scan button. Once the diagram is scanned, the system would use the QR codes to determine the correctness of the solution. The student would then be able to connect the diagram to the computer application or move on to the next challenge. The user would have to complete a total of 5 random challenges of increasing difficulty and would be given a score and the total time. Each time they play, they would be encouraged to try to beat their previous score and time.

Conclusion and Discussion

These applications are important, as programming is a prominent part of our everyday lives and adding these applications will increase the accessibility of different software design techniques to blind programmers. However, while these applications are convenient, they require that the user is experienced/understands creating software. A future direction for learning UML diagrams for visually impaired student programmers is having a physical interactive block version of UML diagrams with Braille. This can be an excellent way to convey UML diagrams to sight loss individuals trying to learn the concept while being novices at programming. It also includes a game to help novices practice their UML diagram building skills.

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Unity

► ROP-Skill System: Model in Serious Games for Universities

Unity, a 2D and 3D Game Engine

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Synonyms

Game engine; Game physics engine

Definitions

Game engine: A game engine is a software framework designed to help developers create video games. A game engine typically includes a graphics engine, a physics engine, an audio engine, and other modules that handle game logic, artificial intelligence, networking, and other aspects of game development.

Game physics engine: A game physics engine is a software library or module that provides the tools and algorithms needed to simulate realistic physics in a video game. A physics engine typically includes a variety of tools and algorithms for simulating physical interactions between objects in the game world, such as rigid body dynamics, soft body dynamics, fluids, and cloth simulations. It also handles collision detection and resolution, which is essential for accurately simulating physical interactions between objects.

Introduction

Unity 3D is a cross-platform 3D computer graphics game engine developed by Unity Technologies. It is used to create 2D and 3D video games, as well as simulations and other interactive content for various platforms such as desktop computers, mobile devices, and virtual reality systems (Axon 2016).

Unity 3D provides a variety of features and tools for game developers, including a visual editor, scripting tools, physics simulation, audio management, and asset management. It supports a wide range of programming languages such as C#, JavaScript, and Boo. It can export to multiple platforms such as Windows, Mac, iOS, and Android.

Unity 3D is known for its ease of use and accessibility to both experienced and novice game developers, making it a popular choice for indie game development as well as large-scale commercial game projects. Its popularity is also

due to its ability to create high-quality graphics, realistic physics simulations, and advanced AI systems, which have made it a top choice for game developers (Dealessandri 2020).

Versions of Unity Game Engine

Unity is a popular game engine that has undergone numerous updates and revisions since its initial release in 2005. Here are the major versions of Unity that have been released:

1. Unity 1.0 (2005)
2. Unity 2.0 (2007)
3. Unity 3.0 (2010)
4. Unity 4.0 (2012)
5. Unity 5.0 (2014)
6. Unity 2017 (2017)
7. Unity 2018 (2018)
8. Unity 2019 (2019)
9. Unity 2020 (2020)
10. Unity 2021 (2021)

Each version of Unity has introduced new features and improvements, such as better graphics rendering, improved physics simulation, and enhanced scripting capabilities. Unity 5.0, for example, introduced physically based shading and improved lighting, while Unity 2019 introduced the Visual Effect Graph and High Definition Render Pipeline (HDRP).

Visual Effect Graph in Unity

The Visual Effect Graph is a feature in the Unity game engine (version 2018 and later) that allows developers to create complex and dynamic visual effects for their games. It is a node-based system that provides a visual interface for creating and manipulating particles, lights, textures, and other graphical elements that make up the visual effects.

The Visual Effect Graph allows developers to create effects that can react to user input, such as explosions that deform the environment, or effects that are triggered by certain game events. It also allows for advanced techniques such as motion blur, depth of field, and temporal anti-aliasing to be added to the game's visuals.

One of the key benefits of the Visual Effect Graph is that it allows for real-time editing and iteration, meaning that developers can see the results of their changes immediately without having to wait for long build times. It also supports GPU instancing and other performance optimization techniques, allowing for complex visual effects to be rendered efficiently.

Unity Game Engine in Hollywood Filmmaking

Unity game engine has been used in several Hollywood films for previsualization, special effects, and postproduction. Here are some examples:

1. The Lion King (2019): The filmmakers used Unity to create a virtual reality version of the African savannah, which they used to previsualize the film's key sequences before filming began.
2. The Jungle Book (2016): Unity was used to create a virtual set for the film, allowing the filmmakers to shoot in a controlled environment and then add the animals and other elements in postproduction.
3. Blade Runner 2049 (2017): Unity was used to create a real-time environment for the film's visual effects team to work in, allowing them to preview and iterate on the effects more quickly.
4. Rogue One: A Star Wars Story (2016): Unity was used to create a real-time preview of a space battle sequence, allowing the filmmakers to make adjustments and refine the sequence before filming began.
5. Captain Marvel (2019): Unity was used to create a virtual reality environment for the filmmakers to use in previsualizing key sequences and planning camera movements.

Licensing Model

Unity offers a variety of licensing options to suit the needs of different types of developers and

organizations. As of 2023, here are the main licensing options for Unity:

1. Unity Personal: This is a free license for individuals and small businesses earning less than $100,000 in annual revenue or funding. It provides access to all of the core features of Unity, but is subject to certain restrictions, such as a revenue cap and limited support.
2. Unity Plus: This is a subscription-based license aimed at small businesses and individual developers who are earning more than $100,000 in annual revenue or funding. It includes additional features and benefits, such as higher revenue caps, priority support, and a license to use Unity for development on mobile platforms.
3. Unity Pro: This is a more advanced license aimed at larger studios and developers who require access to more advanced features and tools, such as source code access, advanced profiling tools, and additional platform support. It is a subscription-based license that requires an annual commitment.
4. Unity Enterprise: This is a customized licensing option for larger organizations and enterprises that require custom features, support, and training. It includes all of the features of Unity Pro, as well as additional support and consultation services.

Unity also offers licensing options for specific use cases, such as educational institutions, nonprofit organizations, and government agencies.

Cross-References

- ▶ Game Engine
- ▶ Game Physics Engine, Overview

References

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Unmanned Aerial Vehicle

▶ Deep Reinforcement Learning in Virtual Environments

Unreal Engine, a 3D Game Engine

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Synonyms

Game engine; Game physics engine

Definitions

Game engine = A game engine is a software framework designed to help developers create video games. A game engine typically includes a graphics engine, a physics engine, an audio engine, and other modules that handle game logic, artificial intelligence, networking, and other aspects of game development.

Game physics engine = A game physics engine is a software library or module that provides the tools and algorithms needed to simulate realistic physics in a video game. A physics engine typically includes a variety of tools and algorithms for simulating physical interactions between objects in the game world, such as rigid body dynamics, soft body dynamics, fluids, and cloth simulations. It also handles collision detection and resolution, which is essential for accurately simulating physical interactions between objects.

Introduction

Unreal Engine is a 3D computer graphics game engine developed by Epic Games. It is used to

create high-quality video games, as well as virtual reality experiences, architecture visualizations, and other interactive content for various platforms such as desktop computers, consoles, and mobile devices (Plante 2012).

Unreal Engine provides a variety of features and tools for game developers, including a visual editor, scripting tools, physics simulation, audio management, and asset management. It supports programming languages such as C++, Blueprints, and Python, and can export to multiple platforms such as Windows, Mac, PlayStation, Xbox, Nintendo Switch, iOS, and Android.

Unreal Engine is known for its powerful graphics capabilities, advanced physics simulation, and AI systems. It allows game developers to create highly immersive and interactive experiences, and is often used for creating high-end, AAA games. It is also popular among indie game developers due to its ease of use and accessibility, and the fact that it is free to use until certain revenue thresholds are met. Overall, Unreal Engine is a top choice for game developers who want to create visually stunning and highly engaging games and interactive experiences.

Versions of Unreal Engine

As of 2023, Unreal Engine has released five versions since its debut in 1998:

1. Unreal Engine 1: Released in 1998, it was used to create first-person shooter games like Unreal and Unreal Tournament.
2. Unreal Engine 2: Released in 2002, it added support for more platforms and advanced lighting and animation features.
3. Unreal Engine 3: Released in 2006, it was a major upgrade with improved graphics, physics, and game development tools. It was used to create popular games such as Gears of War and Batman: Arkham Asylum.
4. Unreal Engine 4: Released in 2014, it was another major upgrade with new features such as a visual scripting language called Blueprint, advanced physics simulation, and improved graphics rendering capabilities. It has been used to create high-profile games such as Fortnite, Borderlands 3, and Final Fantasy VII Remake.
5. Unreal Engine 5: Released in 2021, it introduces a new system called Nanite for rendering high-quality, film-quality graphics in real time, as well as Lumen, a global illumination system that enhances lighting and shadows.

Blueprint in Unreal Engine

Blueprint is a visual scripting system in Unreal Engine that allows game developers and designers to create gameplay mechanics, game logic, and other functionality without needing to write code. It is a node-based system, which means that developers can create complex interactions by connecting different nodes together.

Blueprints use a drag-and-drop interface, making it easy to create and modify game logic. The nodes represent different actions, events, and variables, and can be connected together in a flowchart-like manner to create a sequence of actions. For example, a developer could create a Blueprint that controls the behavior of a character, including movement, animation, and interaction with objects in the game world.

Blueprints also support inheritance and component-based architecture, which allows developers to create reusable components and behaviors that can be easily shared and modified across different parts of the game.

One of the benefits of using Blueprint is that it can help nonprogrammers, such as designers and artists, to create gameplay mechanics and other functionality without needing to learn how to write code. However, it is also a powerful tool for experienced programmers who can use it to quickly prototype and iterate on game ideas.

Unreal Engine Marketplace

The Unreal Engine Marketplace is an online platform where developers can buy and sell game assets, tools, and plugins for use in Unreal Engine.

It was created by Epic Games to provide a centralized location for developers to find high-quality assets and content to use in their games and other interactive projects.

The Marketplace offers a wide variety of assets, including 3D models, textures, sound effects, music, blueprints, plugins, and other game development tools. These assets are created by both individual developers and larger companies, and can be purchased for a fee or, in some cases, downloaded for free.

Using assets from the Marketplace can help developers save time and money by providing them with premade resources that they can use to quickly create and enhance their games. For example, a developer might use assets from the Marketplace to create game levels, character models, or environmental effects.

In addition to offering assets for purchase, the Marketplace also allows developers to sell their own creations to other developers. This can be a way for developers to earn income from their work and build a portfolio of game assets and tools that they can showcase to potential employers or clients.

Overall, the Unreal Engine Marketplace is a valuable resource for developers looking to create high-quality games and interactive experiences using Unreal Engine.

Unreal Engine in Hollywood Filmmaking

Unreal Engine has been used in Hollywood movies and TV shows to create stunning visual effects and virtual environments more cost-effectively. Here are some examples:

1. The Mandalorian: The popular Star Wars TV show on Disney+ used Unreal Engine to create its stunning virtual backgrounds and environments. This allowed the show to film in a much smaller physical space while still achieving the epic scale and detail of the Star Wars universe.
2. The Lion King: The 2019 live-action remake of the Disney classic used Unreal Engine to create the film's virtual environments, which included the African savannah and Pride Rock. This allowed the filmmakers to create photorealistic environments and characters that closely matched the original animated movie.
3. The Jungle Book: The 2016 live-action adaptation of the classic Disney movie used Unreal Engine to create the film's virtual environments and characters, including the lush jungle and its inhabitants. This allowed the filmmakers to create a visually stunning and immersive movie experience.
4. Blade Runner 2049: The sci-fi sequel used Unreal Engine to create its futuristic cityscapes and environments. This allowed the filmmakers to create a detailed and immersive world that felt like a natural extension of the original Blade Runner movie.

Licensing Model

Unreal Engine has a unique licensing model that offers developers different options based on their needs and budget. Here are the main licensing options:

1. Royalty based: This is the default licensing option for Unreal Engine. Under this model, developers can use the engine for free, but must pay a 5% royalty on gross revenue for any commercial products they create using the engine. With Unreal Engine 5, however, Epic Games waives their royalties margin for games until developers have earned US$ one million in revenue (Machkovech 2020) and the fee is waived if developers publish on the Epic Games Store.
2. Custom licensing: Epic Games also offers custom licensing options for large game studios or companies that have specific needs or require more flexibility than the royalty-based model provides. This option allows developers to negotiate their own licensing terms and can include options such as flat fees, custom support, and other services.
3. Unreal Studio: Unreal Studio is a suite of tools and plugins designed for architectural

visualization, product design, and other non-game applications. It offers a different licensing model which is subscription based and provides access to a range of additional features and support options.

Cross-References

- ▶ Game Engine
- ▶ Game Physics Engine, Overview

References

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Unsportsmanlike Behavior

- ▶ Toxic Behaviors in Online Gaming

Usability

- ▶ Immersive Technologies for Accessible User Experiences

Usability Design and Evaluation

- ▶ User-Centered Design and Evaluation Methodology for Virtual Environments

User Acoustics

- ▶ User Acoustics with Head-Related Transfer Functions

User Acoustics with Head-Related Transfer Functions

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Synonyms

Binaural hearing; Binaural sound; Head-related impulse response; Head-related transfer function; HRIR; HRTF; ILD; ITD; Spatial hearing; User acoustics

Definitions

Head-related impulse responses (HRIRs) or head-related transfer functions (HRTFs, in the frequency domain) describe spatial-temporal acoustic properties of a human body resulting from the interaction of user's head, ear, and torso with the sound-field in space. The synthesis of a binaural anechoic spatial sound can be obtained by the convolution of an anechoic sound signal with left- and right-ear HRTFs chosen among a discrete set of measurements, i.e., spatial locations. Binaural and monoarual localization cues contained in the HRTFs allow users to experience a 360° spatial audio experience, being fundamental component for the immersive and realistic auralization in virtual/augmented reality and games.

Introduction

Multisensory integration is all the more vital in spatial perception where auditory cues assist visual attention for seeking potential dangers around primates and mammals (Holmes and Spence 2005), apprehending location and movements of a potential prey and communicating between peers (Gridi-Papp and Narins 2008). Human hearing incorporates perception of loudness, pitch, timbre, and spatial attributes of sound.

In particular, the auditory system is capable of estimating the location of sound sources in terms of direction and distance, as well as the spatial impression from the surrounding acoustic space. The position and movement of the listener inside the environment plays a key role in the perception of the characteristics of the listening space be it real or virtual.

Binaural anechoic spatial sound can be obtained by convolving an anechoic sound signal with left and right HRTFs over a discrete grid of spatial measurement points for a given listener and interpolated in order to synthesize arbitrary spatial locations (Xie 2013) (see Fig. 1a for a general schematic view of auralization). The minimum-phase characteristic of HRTF allows its decomposition in a pure delay, τ, followed by a minimum-phase system, $H_{\min}$:

$$H(\theta,\phi,r,\omega) = H_{\min}(\theta,\phi,r,\omega) \exp[-j2\pi f\tau(\theta,\phi,r,\omega)]. \quad (1)$$

where θ and ϕ denote source direction of arrival (DOA) in spherical coordinates and r source distance from listener head. Auralization algorithms largely benefit from this decomposition in terms of stability and performances (Schissler et al. 2016). The pure delay/time-shift can be defined as the monaural time of arrival (TOA), allowing inter-aural time difference (ITD) extraction considering the difference between left and right ear TOA. With the inter-aural level/intensity difference (ILD/IID), they are the basis of duplex theory for binaural lateralization of sound (Strutt 1907). In particular, ILD can be formally described by the following equation:

$$\mathrm{ILD}(\theta,\phi,r,f) = 20\log_{10}\left|\frac{P_R(\theta,\phi,r,f)}{P_L(\theta,\phi,r,f)}\right|, \quad (2)$$

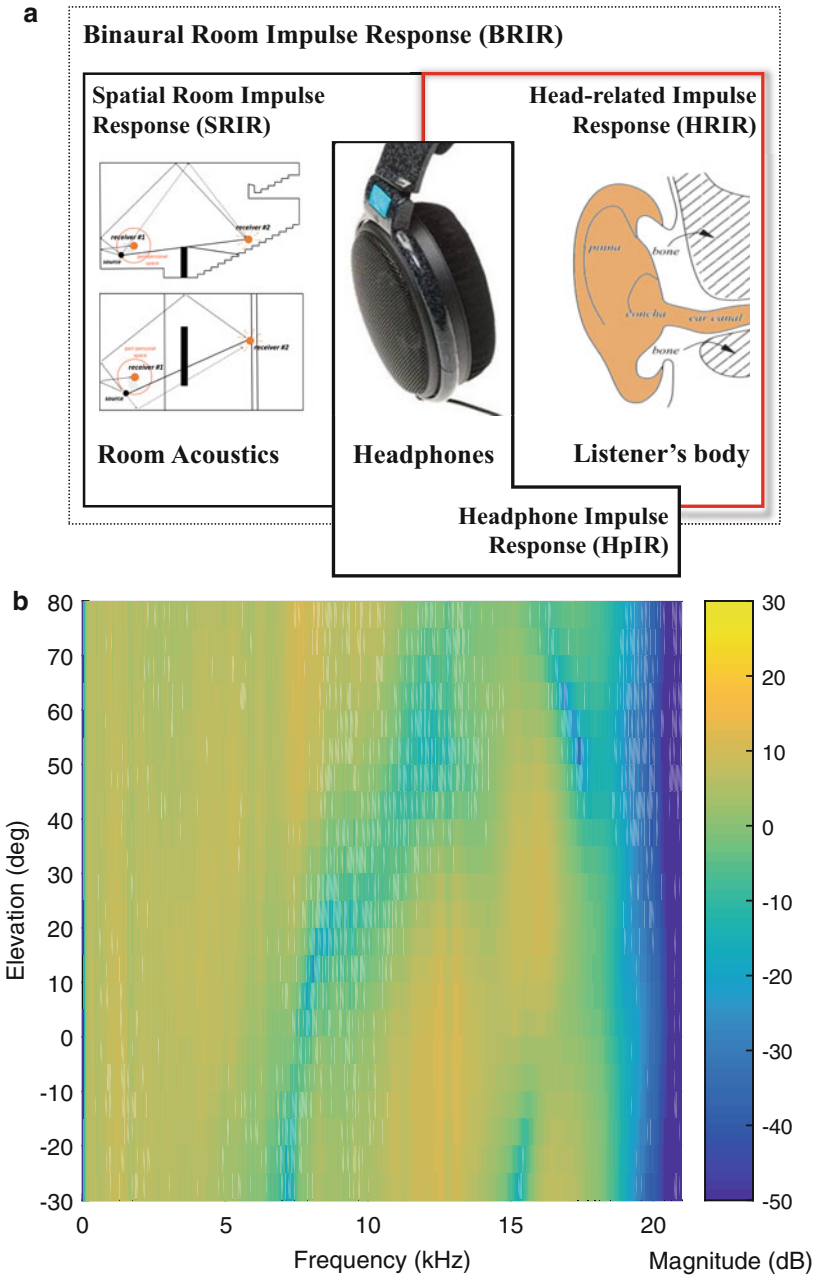
where $P_{L/R}$ indicates the sound pressure in the frequency domain generated by a sound source in a given spatial position at the left/right ear. ILD is relevant for high frequencies where the wavelength is smaller than the physical dimensions of the head, shadowing sound pressure at contralateral side. Dynamic localization cues due to head movements further strengthen ITD/ILD combination; accordingly, embedded IMU sensors in VR headsets become crucial for effective head-tracking and auralization.

Looking at the magnitude of $H_{\min}$ (see Fig. 1b for an example), Romigh and Simpson (2014) recently identified the intraconic spectral component as the main cause of inter-individual differences where pinna acoustics becomes dominant for localization in elevation. However, recording individual HRTFs of each user requires a trade-off between resources and time, because the measurement process is heavily prone to errors, and nowadays its complexity results unmanageable for any real-world application.

In multimodal virtual environments, a common approach is to use the same generic HRTFs, e.g., recorded using a dummy head such as Neumann KU-100 (see Fig. 2 for some visual examples), for any listener in order to obtain a trade-off between average efficacy and measurement/personalization procedures taking into account the dominance of visual cues for localization. However, generic HRTFs generally introduce unnatural coloration in the frequency spectrum and degradations in localization and immersion of the listening experience. Paul (2009) provided an historical review on this topic.

HRTF Personalization and Adaptation

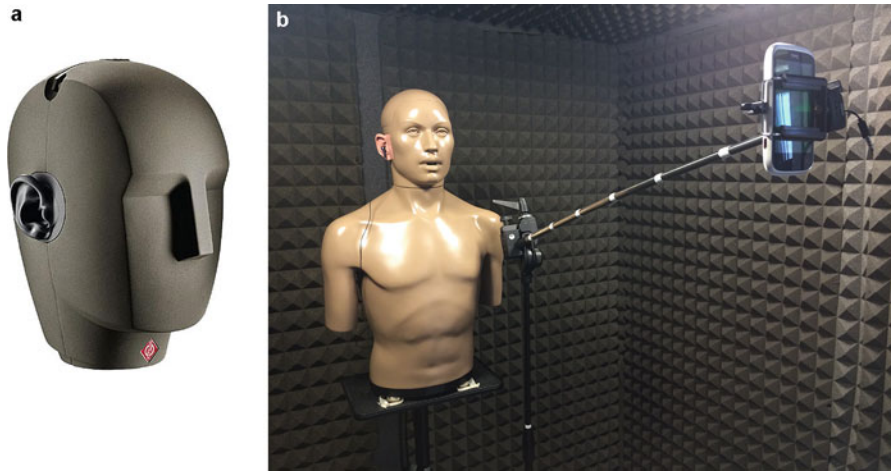
Dummy-head HRTFs can be considered an average template for user acoustics, introducing high uncertainty in localization due to differences with user anthropometry and to individual abilities in encoding generic directional information. Manipulating such HRTF template in order to personalize user acoustic contribution gives rise to different strategies: from the frequency scale factor based on anthropometric differences (Middlebrooks 1999) to ITD individualization with scaling procedures (Lindau et al. 2010), to name but a few. Moreover, one can allow users to directly manipulate a HRTF template using a series of bandpass filters to boost or attenuate specific frequency bands (Tan and Gan 1998). The post-manipulation phase usually requires user's involvement with



User Acoustics with Head-Related Transfer Functions, Fig. 1 (**a**) High-level acoustic components for VR auralization with focus on user acoustics. (**b**) Example of head-related transfer function variability for elevation in the frontal mid-sagittal plane of a Neumann KU-100 dummy-head. (Data taken from international research project "Club Fritz" (Andreopoulou et al. 2015))

listening tests in order to further iterate the process until the desired level of efficacy is obtained.

Recent literature is increasingly investigating the development of personalized HRTFs for each individual user in virtual/augmented reality in order to support a listening experience which is perceptually equivalent to that with own individual HRTFs. HRTFs can be computed from basic



User Acoustics with Head-Related Transfer Functions, Fig. 2 (**a**) Neumann KU-100 dummy head. (**b**) Example of a measurement setup on a KEMAR dummy head for HRTF personalization in the "SelfEar project" Geronazzo et al. (2016)

geometry of the head, pinna, shoulders, and torso and/or accurate numerical simulations with boundary element (BEM) and finite-difference time-domain (FDTD) methods (Xie 2013; Prepelita et al. 2016). Moreover, a structural interpretation of the acoustic contribution of head, pinna, shoulders, and torso can guide filter modeling of time and spectral (e.g., peaks and notches) variations (Geronazzo et al. 2013). HRTF features can be also defined according to principal component analysis (PCA) and subsequently personalized with self-tuning actions of weights (Hwang et al. 2010).

On the other hand, optimized selection procedures of existing nonindividual HRTFs is an alternative approach to personalization in which HRTFs are chosen by selecting the best match among several HRTF sets in a database. These approaches can benefit from the exponential increase of available HRTF data during the last 10 years, which has also provided motivations for standardization processes such as the Spatially Oriented Format for Acoustics (SOFA) (Majdak et al. 2013) (see also the official website of the SOFA project http://sofaconventions.org/ for an exhaustive list of freely available HRTF databases).

A user can select existing HRTFs in the domains of acoustic information, anthropometric features, and listeners subjective ratings (e.g., the most selected nonindividual HRTFs for a large user population). These procedures can be both automatic or guided by short listening tests aimed to assess the perceptual impact of nonindividual HRTFs for a given user. A training phase usually allows adaptation to nonindividual HRTFs thanks to automatic feedback such as correct-answer information to localization errors or audio-visual feedback adjustments. It is worthwhile to notice that there exist users able to better localize with nonindividual rather than individual HRTFs after an adaptation procedure (Klein and Werner 2016).

Conclusions

The need of a proper characterization of user acoustics is a key element for a realistic rendering in virtual reality scenarios, and it is even more crucial in immersive augmented reality settings where real and virtual sound sources are mixed in a natural listening experience (Ranjan and Gan 2015). Ensuring real life localization performances in VR becomes more and more important with close relations to presence, task-relevance, and effectiveness of the experience. Accordingly, users can increase their localization skills through

adaptation procedures directly in VR games which act as a training tool for remapping localization cues with nonindividual HRTF (Parseihian and Katz 2012).

Cross-References

- Immersive Auralization Using Headphones
- Overview of Virtual Ambisonic Systems
- Sonic Interactions in Virtual Environments
- Sound Spatialization
- Spatial Perception in Virtual Environments
- Training Spatial Skills with Virtual Reality and Augmented Reality

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User Experience

▶ Immersive Technologies for Accessible User Experiences
▶ Mixed Reality and Immersive Data Visualization

User Experience in Autonomous Driving

▶ User Interface (UI) in Semiautonomous Vehicles

User Interaction

▶ 3D Selection Techniques for Distant Object Interaction in Augmented Reality
▶ Computer Graphics, Video Games, and Gamification Impacting (Re)Habilitation, Healthcare, and Inclusive Well-Being
▶ Object Manipulation Using Real Hand Gesture for Augmented Reality Interior Design

User Interface (UI) in Semiautonomous Vehicles

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Synonyms

Intelligent transportation systems; Trustworthy autonomous vehicles; User experience in autonomous driving; User interface in autonomous driving

Definition

Autonomous vehicles refer to vehicles equipped with advanced technology that allows them to operate and navigate without human interference. These vehicles are designed to sense their environment using various sensors and make decisions based on the collected data. Autonomous vehicles utilize artificial intelligence and sophisticated algorithms to perceive their surroundings, interpret information, and control their movement accordingly.

Semi-autonomous vehicles, also known as partially autonomous vehicles or Level 2/3 autonomous vehicles (according to the SAE International classification), are vehicles that blend automated driving capabilities with human control. Unlike fully autonomous vehicles, semi-autonomous vehicles require the presence of a human driver who is responsible for monitoring the driving environment and being prepared to take over control if needed.

Trust in the concept of autonomous vehicles refers to the confidence, belief, and reliance that individuals or society as a whole have in these vehicles to perform their intended functions safely, reliably, and efficiently. It encompasses the level of faith people have in the capabilities and performance of autonomous vehicles, as well as their perception of the technology's overall reliability, security, and ethical considerations.

Introduction

Autonomous vehicles are intelligent systems that are able to adapt continuously to their surrounding environment and move by sensing it (Yu et al. 2019) and without being interfered by human input (Fridman 2018; Wang et al. 2021). They are designed in six different levels of operation, including (1) No Automated driving, (2) Driver Assistance, (3) Partial Automation, (4) Conditional Automation, (5) High Automation, and (6) Fully Automated Driving (SAE 2014; Wang et al. 2021).

The focus of this entry is on fully automated cars. These vehicles usually work considering

User Interface (UI) in Semiautonomous Vehicles, Table 1 How autonomous vehicles work (Barber 2022)

Perception	Prediction	Planning
What is this object? Where is it?	Where will it go?	How do I navigate?

three main concepts: (1) perception, which means finding out what are these objects around the vehicle at different angles and where are their exact location, (2) predicting where they will go; and (3) planning how the vehicle navigates to reach the destination (Barber 2022) (Table 1).

One of Artificial Intelligence's (AI) most significant challenges is making technologies interactable, without struggle and challenges, and making design transparent and immersive (Steven 2017). For example, although using a self-driving car seems fun, interacting with these vehicles is not always easy. The imagination of future autonomous cars with perfect User Interface (UI) might seem impossible; one might enter the car, order it where to go, chill, watch a movie, or take a nap. In individuals' imagination, it sounds fancy. However, the problem is complex and needs to be examined using passengers' experiences in different aspects to design and implement a more user-friendly self-driving car (Steven 2017).

This entry covers state-of-the-art technologies and discusses the current thoughts on user interface and user experience design in autonomous cars. This entry aims to propose the important concepts and issues of developing a fully automated vehicle in terms of UI design.

UI in Semiautonomous Vehicles

Considering the interactions in autonomous vehicles, state-of-the-art Human-Computer Interaction (HCI) technologies refer to the design of control transitions from the driver to the automated vehicle. Moreover, automated vehicles need to support tasks unrelated to driving once the drivers are assumed to be passengers in the car (Pfleging et al. 2021). The first important issue in this process is whether the passenger can trust the automated vehicle or not. To improve the trustworthiness of autonomous vehicles, it is important to increase the interaction between passengers and the vehicle through user interfaces.

Trust

Through the transition toward automated vehicles, new challenges are expected as the responsibilities are shifted from the driver to the vehicle. Implementing shared control between them also raises some challenges in semiautomated vehicles. Some of these challenges are creating and maintaining situational awareness and finding solutions to build trust while maintaining user acceptance of automation technology (Pfleging et al. 2021). As a passenger in a manual car, you can easily interact with the driver and ask them where they are going, or in case you are the driver, you know that you are in control of everything. Also, people and other drivers will know that the car has a driver who is careful about them and knows the rules. So, in a word, there is trust, and when the vehicle does not have a driver, it is harder to trust it. Consider a bicyclist riding on the road; when they see a car that wants to turn, they will make eye contact with the driver and ensure that the person notices them. Even the drivers may show them with their hands that they are waiting for them to pass. All these clues assure people in the street that they are safe around this car. Considering these examples, to build trust in automated vehicles, there is a need to predict the next action and a need to communicate (Steven 2017).

Communication Design

Once the control and responsibilities are shifted to the automated vehicle, a new challenge is to develop systems to communicate with pedestrians, cyclists, or drivers of manually driven vehicles (Pfleging et al. 2021). The passengers in autonomous cars are probably involved with non-driving-related tasks, and therefore, they do not monitor the road. In such a situation, other road users may not be able to communicate with the driver, and technical solutions are crucial to

replace the traditional form of communication with a new one. The influence of such communication concepts on driving behavior, traffic flow, and social acceptability can play an essential role in future traffic situations. To address this issue, there is a need to see what the machine sees and gets as input. However, just visualizing all the data that sensors gather could be confusing and is not enough. For example, there is a need for a user-friendly Human Machine Interface (HMI) to be developed so that a user with no experience in object detection or working with sensors can understand. So the user interfaces should be simple, straightforward, and correct.

While it should have this intractable simulated surrounding, it also should be informative enough for both driver and passengers. Similar to all the regular navigation applications, information about the traffic, the remaining distance, and the time to reach the destination should be provided for passengers. Moreover, specific information about the car's working status, like speed and battery situation, is also crucial.

Interior Design

While passengers are not busy driving in the car, there might be a need to provide entertainment for passengers in the vehicle (Sener and Bahar. 2020). To explain more, the interior should convert into an office, living room, or dining room, or may even support relaxation and sleeping (at least in the far future) to allow the passengers to take advantage of the free time they have during their trip. This automatically leads to reconsidering some factors ranging from redesigning the car's interior based on their needs to employing modern materials to create and facilitate the ride for both passengers and drivers (Pfleging et al. 2021).

This is the point that the role of infotainment becomes even more important, which we will discuss in the following chapter.

Literature Review

Research about different aspects of autonomous vehicles is still attracting academic attention. In the case of user experience design for autonomous cars, different research was conducted to determine how passengers' experiences can lead us to design and implement a more user-friendly self-driving car. In Sen and Umulu's work, a workshop was held to ask participants in an experiment to examine different scenarios to define activities that an infotainment system could make in separate modes, which is trying to enhance UI features and functionality in semi-autonomous cars. Various modes are described in the (Sen and Umulu 2021) paper, whether the passenger chooses to interact with the infotainment system, pay more attention to the surroundings, or consider both. Therefore, the UI system will work on the passenger's priority. When passengers are completely informed about the trip and what the car is doing, our motivation for improving this kind of infotainment system in autonomous vehicles is to let the passengers have a connection to social media, interact with other cars, and not feel excluded from the journey (Ohad and Noam 2011; Sener and Bahar 2020). These issues are not only happening in autonomous cars but also in regular cars. For example, in Berger and Collab's work, an interactive car window and door panel are introduced to help the passenger in the rear seat to interact more with the surroundings (Berger et al. 2021).

Conclusion and Discussion

In conclusion, the main points that should be considered in UI in autonomous vehicles are as follows:

First, self-driving cars are not a dream anymore, and now the new challenge is improving UI and UX design for these vehicles. Second, better UI design will result in more trust in self-driving cars, which is crucial for autonomous vehicles. And finally, UI/UX design for autonomous vehicles is not just limited to the technical representation of the trip but also includes all the personal aspects related to the driver, like making the person informed, entertained, and involved.

Cross-References

- ▶ Potential of Augmented Reality for Intelligent Transportation Systems
- ▶ Virtual Reality Exercise and Rehabilitation

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User Interface in Autonomous Driving

▶ User Interface (UI) in Semiautonomous Vehicles

User-Centered Design and Evaluation

▶ User-Centered Design and Evaluation Methodology for Virtual Environments

User-Centered Design and Evaluation Methodology for Virtual Environments

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Synonyms

Iterative design; Project management; Project planning; Requirements analysis; Requirements specification; Usability design and evaluation; User-centered design and evaluation; Virtual reality development methodology

Definitions

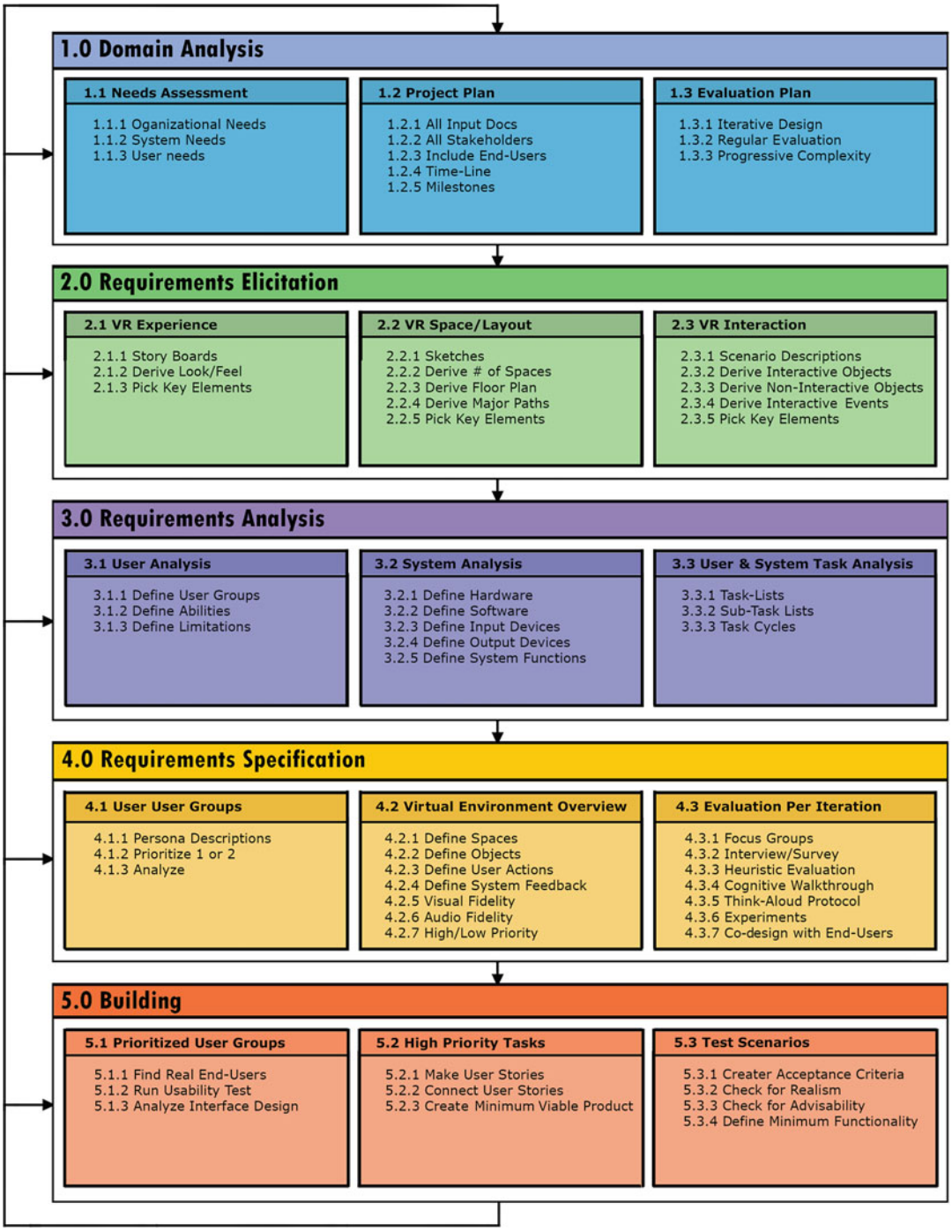
User-driven development framework for virtual reality setups: a development methodology for virtual reality systems, that puts the user central

in a cyclical development process, iteratively clarifying the usability goals for the setup in terms of the user, system, and organizational characteristics and needs, and systematically matching these onto the technologies, interfaces, and processes to be developed, in order to achieve a time- and cost-effective development process, and a VR Setup with a satisfactory user experience, with efficient task and workflow, giving extensive attention at each stage of the design process to evaluating the user experience and user interface.

User-Centered Software Development for VR

The user-centered software development methodology framework consists of systematic information elicitation and documentation, in incrementally more detailed stages and using progressively more complex information elicitation activities, as summarized in the text and diagram below. User-centered software development progresses in an iterative process of clarification and refinement of the application requirement descriptions, based on input and feedback from all stakeholders, product owners, and representative end-users. User- and system-requirements information is continuously collected from them and then analyzed and documented by the development team. The team ideally consists of one or more user interaction designers, user interface developers, software developers, and preferably at least one representative end-user (Eastgate et al. 2014; Tromp et al. 2003). All requirements analysis information is documented in the requirements specification, in order to create a common and clear reference document for the development tasks and help manage and coordinate collaboration within the team. Development can start as soon as a first pass has been made through the framework and the minimum viable product (MVP) specification has been described. Not all details for the application can be known in the first or second pass through the framework. Often details only become apparent after several passes through the framework, which is why this methodology is an iterative development process. Similarly, in the early phases of the development process, the user-centered tests will take place on simple or partial prototypes. With each pass through the framework, testing methods will be more complex, in order to assess the progressively more detailed prototypes. This user-centered development methodology framework helps to focus from the start of the development process, on the needs and expectation of the end-users of the application, and it helps to structure the way in which the development team collaborates. The diagram of the framework for this development methodology (see Fig. 1) shows the stages of the development process and the procedural feedback loops, going back to all previous stages, signifying the continuous iterative refinement of the information needed for the development of the user experience, user interface, and system functions.

- **0. Project Brief:** Identify the existing description of the project and use it as the starting point
- **1.0 Domain Analysis:** Create a model of the wider use context of the system
  - **1.1 Needs Assessment:** Assess the current conditions of use and the desired conditions
  - **1.1.1 Organizational Needs:** Identify the skills gap when introducing new VR system
  - **1.1.2 System Needs:** Evaluate technical tasks and functions that the new technology must meet
  - **1.1.3 User Needs:** Measure the gap between current use conditions and the desired conditions
  - **1.2 Project Plan:** Establish the scope, objectives, and steps to achieve the goals of the project
  - **1.2.1 All Input Documents:** Gather all preceding documents that relate to the proposed system
  - **1.2.2 All Stakeholders:** Identify all parties involved in the project and collect their bios
  - **1.2.3 Include End-Users:** Identify and invite representative end-users to all meetings
  - **1.2.4 Timeline:** Create visual overview of project activities for successful project management
  - **1.2.5 Milestones:** Mark points on timeline to signal start/end, iterations, reviews, sprints



User-Centered Design and Evaluation Methodology for Virtual Environments, Fig. 1 Methodology for consistent user-centered design and evaluation methodology for virtual environments

- **1.3 Evaluation Plan:** Identify user-centered evaluation questions and outputs to assess progress
  - **1.3.1 Iterative Testing:** Create cyclic user-centered process: prototype, test, analyze, refine

  - **1.3.2 Regular Testing:** Break down the development of the application into smaller chunks/sprint
  - **1.3.3 Progressive Complexity:** Build more complex features in self-contained development cycles
- **2.0 Requirements Elicitation:** Collect requirements for the VR system from end-users and stakeholders
  - **2.1 VR Experience:** Explore the end-user's attitudes in terms of the practical and meaningful use
  - **2.1.1 Storyboards:** Create a graphic organizer of illustrations and images, colors, and textures
  - **2.1.2 Derive, Look, and Feel:** Identify concept art from the storyboards early in the design process
  - **2.1.3 Pick Key Elements:** Select the minimum viable product elements to be designed first
  - **2.2 VR Spaces / Layout:** Plan structure of virtual world, 3D model, and interactive boundaries
  - **2.1.1 Sketches:** Create sketches of all VR spaces, structures, objects, and events
  - **2.2.2 Derive # of Spaces:** Decide on the number of micro and macro 3D spaces to be modeled
  - **2.2.3 Derive Floorplan:** Decide on layout of VR space plus structures and objects in each space
  - **2.2.4 Derive Major Paths:** Decide on the desired user paths through the VR spaces and events
  - **2.2.5 Pick Key Elements:** Select the minimum viable product elements to be designed first
  - **2.3 VR Interaction:** Define user "avatar"; viewpoints; interactions with VR world and3D objects
  - **2.2.1 Scenario Descriptions:** Create a short written narrative of the desired sequence of events
  - **2.3.2 Derive Interactive Objects:** Identify 3D objects, interactivity, level of detail, and visual fidelity
  - **2.3.3 Derive Noninteractive Objects:** Identify 3D objects as decor for high believability
  - **2.3.4 Derive Interactive Events:** Identify sequence of events on and between each location
  - **2.3.5 Pick Key Elements:** Select the minimum viable product elements to be designed first
- **3.0 Requirements Analysis:** Analyze, validate, and combine requirements of stakeholders and end-users
  - **3.1 User Analysis:** Determine the characteristics and needs of all users of the VR system
  - **3.1.1 Define User Groups:** Identify different user groups, such as end-users, installers, servicers
  - **3.1.2 Define Abilities:** Clarify the abilities of each user group in terms of using the new VR system
  - **3.1.3 Define Limitations:** Clarify limitations of each user group in terms of using the VR system
  - **3.2 System Analysis:** Determine the procedures and processes and how to improve them
  - **3.2.1 Define Hardware:** Identify the physical components: visual, haptic, and tracking devices
  - **3.2.2 Define Software:** Identify VR world engine, 3D object generators, test the interoperability
  - **3.2.3 Define Input Devices:** Identify desired sensors, trackers, haptic devices for direct interaction
  - **3.2.4 Define Output Devices:** Identify desired visual, haptic, auditory, equilibroception displays
  - **3.2.5 Define System Functions:** Check input, output, processing, and storage functions needed
  - **3.3 User and System Task Analysis:** Identify tasks are performed by the user and by the system
  - **3.3.1 Task Lists:** Create a numbered hierarchical task analysis to define all tasks to be developed

  - **3.3.2 Subtask Lists:** Break each task down into all its subtasks until everything is defined
  - **3.3.3 Task Cycles:** Identify task cycles and system feedback to lead users through tasks
- **4.0 Requirements Specification:** Describe the functional and nonfunctional elements of the VR system
  - **4.1 User Groups:** Describe requirements per user group, include tailored use cases
  - **4.1.1 Persona Descriptions:** Describe end-user behaviors, goals, skills, attitudes, and expectations
  - **4.1.2 Prioritize One or Two:** Select most important user group(s) for the minimum viable product
  - **4.1.3 Analyze:** Derive from persona description the requirements for the user experience
  - **4.2 Virtual Environment Overview:** Describe in full detail what the VR world contains
  - **4.2.1 Define Spaces:** Describe in full detail the spaces for the VR world
  - **4.2.2 Define Objects:** Describe in full detail the objects for the VR world
  - **4.2.3 Define User Actions:** Describe the user actions in the VR world and with the VR setup
  - **4.2.4 Define System Feedback:** Describe the system feedback to guide user interactions
  - **4.2.5 Visual Fidelity:** Describe level of detail and realism for 3D objects and spaces of the VR world
  - **4.2.6 Audio Fidelity:** Describe the level of detail and style of ambient sound and feedback sounds
  - **4.2.7 High/Low Priority:** Select minimum viable product elements to define high/low priority
  - **4.3 Evaluation Per Iteration:** Describe which type of evaluation will take place when
  - **4.3.1 Focus Groups:** Include this method at the beginning of the project to clarify end-user opinions
  - **4.3.2 Interviews/Survey:** Include at the beginning of project to clarify user and organizational needs
  - **4.3.3 Heuristic Evaluation:** Use to evaluate prototypes before it is ready for end-user evaluations
  - **4.3.4 Cognitive Walkthrough:** Use to evaluate prototypes before it is ready for end-user testing
  - **4.3.5 Think-Aloud Protocol:** Use for detailed evaluations with developers and real end-users
  - **4.3.6 Experiments:** Use to clarify which design solutions are better than others
  - **4.3.7 Co-design with End-User:** Use to refine the design of the user experience
- **5.0 Building:** Create a continuously more complex minimum viable product in several iterations
  - **5.1 Prioritized User Group(s):** Focus on creating the functionalities for this user group first
  - **5.1.1 Find Real End-Users:** Make sure to design and test with representative end-users
  - **5.1.2 Run Usability Tests:** Make sure testing takes place as planned
  - **5.1.3 Analyze Interface Design:** Check all interactive features thoroughly
  - **5.2 High Priority Tasks:** Select the tasks that are essential for the minimum viable product
  - **5.2.1 Make User Stories:** Write user stories or use cases that define the essential functions
  - **5.2.2 Connect User Stories:** Combine the functionalities of each user story or use case
  - **5.2.3 Create Minimum Viable Product:** Iteratively and incrementally more detailed functionality
  - **5.3 Test Scenarios:** Run user tests based on the actual context of use
  - **5.3.1 Create Acceptance Criteria:** Define what needs to work in order to pass the evaluation tests
  - **5.3.2 Check for Realism:** Make sure acceptance criteria are realistic

- **5.3.3 Check for Advisability:** Make sure acceptance criteria are within scope of the project
- **5.3.4 Define Minimum Functionality:** Describe each incremental minimum viable product stage

Cross-References

- ▶ 3D Avatars in Virtual Reality Experience
- ▶ Eye Tracking in Virtual Reality
- ▶ Player-Avatar Link: Interdisciplinary Embodiment Perspectives
- ▶ Virtual Reality-Based Daily Scrum Meetings
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UV Map

- ▶ UV Map Generation on Triangular Mesh

UV Map Generation on Triangular Mesh

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Synonyms

Mesh parameterization; Parameterization; Spectral analysis; UV map

Definition

UV map is a bijective mapping from a surface to a 2D domain. Each vertex on the surface has XYZ coordinates representing the position of a space. The corresponding vertex in 2D domain has UV coordinates ranging from 0 to 1.

Triangular mesh is a collection of vertices, edges, and faces that describes a 3D shape in computer graphics. Most of parameterization methods give a restriction that the input mesh should be a 2-manifold.

Introduction

UV Map generation is an essential process in 3D modeling. Given two surfaces with the same topology, the bijective mapping between them is called mesh parameterization so that UV map is a special case of mesh parameterization. Many applications such as texture mapping, morphing, mesh completion, model compression, remeshing, etc., need a good UV map as a prerequisite. A good UV map is characterized by following properties:

Low stretch. UV map usually has a degree of distortion in order to keep the topology. A low-stretch parameterization is approximately isometric that avoids changing area and angles of each triangular face. To obtain high resolution texture mapping or other benefits in particular applications, low-stretch UV map provides a solid foundation.

Low charts number. Atlas-based UV map, composed of several nonoverlapping free boundary charts, is used for various 3D modeling techniques (e.g., normal map, remeshing, morphing, etc.). A small amount of charts, however, cause more stretch while combining two small charts into a big one provide the integrity of a chart which representing one semantic part of the 3D model after parameterization.

Reasonable cuts. Triangular mesh, achieved by artificial design or computer synthesis, is a generally complete and continuous surface that

needs to be cut into minor parts before parameterization. The seam between two charts should be as invisible as possible so that it is supposed to cut on sharp angle boundary and in low visibility region, rather than in high detailed area.

A large number of research on surface parameterization have been published. Hormann et al. (2008) gives a survey in early year. Angle preserving method including ABF++ (Sheffer et al. 2005), stretch-driven method like iso-charts (Zhou et al. 2004), almost isometric method (Pietroni et al. 2010), quantized global method (Campen et al. 2015), etc., perform well in practical application. A novel UV Map generating method proposed recently allow parameterization can be represented in different levels-of-detail (Tarini 2016). This chapter will introduce a traditional method that generates a UV map under a user-assigned distortion threshold.

Stretch-Driven Mesh Parameterization

To generate an ideal UV map, a constrained stretch value is assigned by user. Two norms of stretch were proposed in Sander et al. (2001). The L_2 norm integrates over the surface where there are largest and smallest singular values of the Jacobian corresponding to the affine matrix which representing the mapping from texture space to model space at any point. The $L\infty$ norm maximizes $\{\gamma_{max}, 1/\gamma_{min}\}$ over the surface. Spectral Analysis proposed by Zhou et al. (2004) was one of the most popular stretch-driven mesh parameterization algorithms. It is composed of following parts:

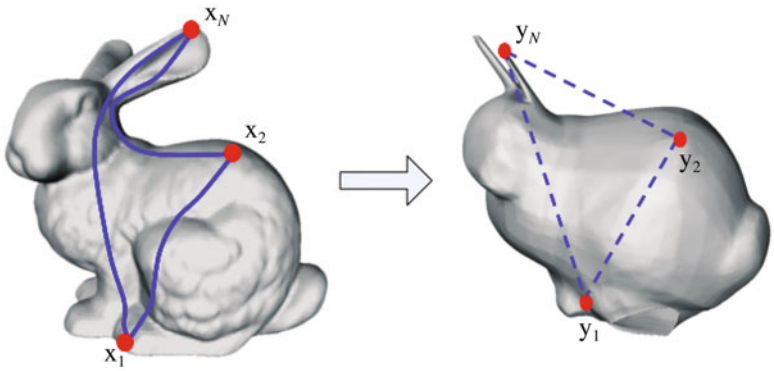
1. Compute the surface analysis as the initial parameterization
2. Perform iterations of stretch optimization (Sander et al. 2001.
3. Split surface into charts using spectral clustering
4. Optimize chart boundaries using signal-based graph cut
5. wPlace charts into a 2D space with UV coordinates to generate an atlas-based UV map

Spectral Analysis

Given a set of points on a high-dimensional manifold, Isomap (Tenenbaum et al. 2000) computes geodesic distances along the surface. Then it finds an embedding in a low-dimensional space whose Euclidean distances are similar to the corresponding geodesic distance in high-dimensional space. Figure 1 shows an example of spectral analysis.

Spectral analysis is built upon Isomap, containing following steps:

1. Given a surface with N vertices, $\mathbf{x}_i$, compute squared geodesic distance between each pair of



UV Map Generation on Triangular Mesh,
Fig. 1 Spectral analysis for the Stanford bunny. Left one is origin model. Right one is the model after spectral analysis in three-dimensional embedding space. The geodesic distance in left one is similar to the Euclidean distance in right one

vertices along the surface. A symmetric matrix $\mathbf{D}_N$ represents these geodesic distance data.
2. Normalizing $\mathbf{D}_N$ using identity matrix $\mathbf{I}$ and centering matrix $\mathbf{J}_N$

$$\mathbf{B}_N = -\frac{1}{2}\mathbf{J}_N\mathbf{D}_N\mathbf{J}_N,$$

where $\mathbf{J}_N = \mathbf{I} - \frac{1}{N}\mathbf{1}\mathbf{1}^{\mathrm{T}}.\mathbf{1}$ is a vector of ones of length N.

3. Compute eigenvalues λ_i and their corresponding eigenvectors $\mathbf{v}_i$.
4. For each vertex $\mathbf{x}_i$, embed it in a new N-dimensional space. The new vector $\mathbf{y}_i$ is

$$\mathbf{y}_i^j = \sqrt{\lambda_j}\mathbf{v}_j^i.$$

Not all of N vertices are needed to represent the energy of the surface. Actually top five eigenvalues constitute over 85% of the squared energy. Therefore, *n-dime*nsional embedding space is recommended for spectral analysis. n is calculated by dominant energy (Zhou et al. 2004).

The distortion of each embedded vertex i called geodesic distance distortion(GDD) can be defined as:

$$GDD(i) = \sqrt{\frac{1}{N-1}\left(\sum_{j=1}^{N}\left\|\mathbf{y}_i - \mathbf{y}_j\right\| - d_{geo}(i,j)\right)^2},$$

where $d_{geo}(i, j)$ is the geodesic distance between i and j. The key idea of parameterization using spectral analysis is setting $n = 2$ to minimize the sum of squared GDD over all vertices (Zigelman et al. 2002).

Stretch Optimization

To minimized $L2$ and $L\infty$ after initial parameterization, Sander et al. (2001) exploit a uniform-edge-spring solution and then perform several optimization iterations.

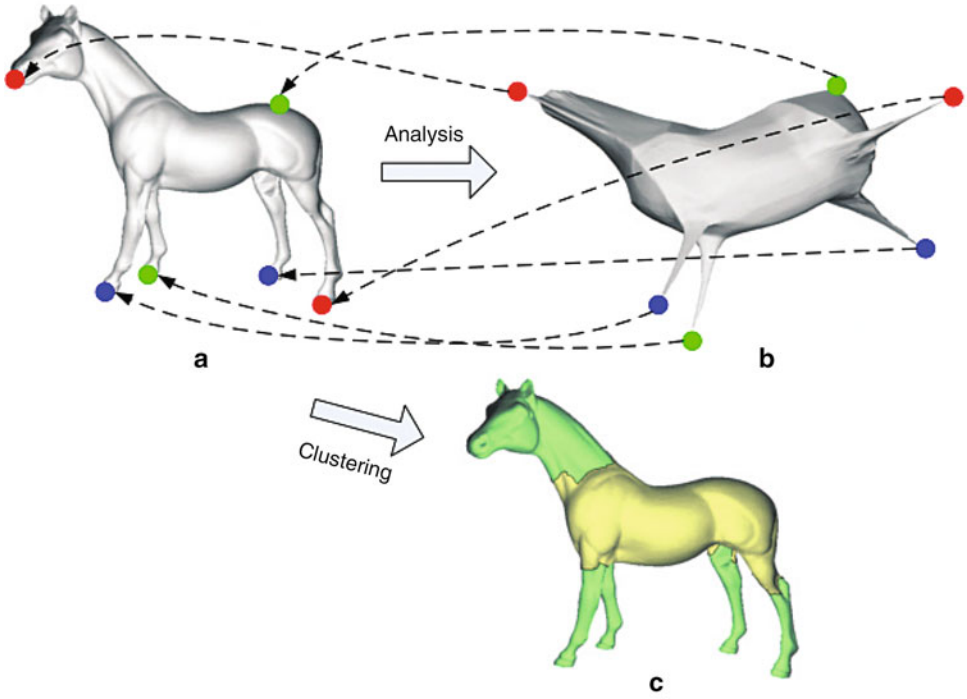
For each iteration, choose the vertices by decreasing order of neighborhood stretch. Then perform a line search minimization along a random direction in texture space. The line search is constrained within the kernel of neighbor because the metric is infinite for degenerate or flip triangles. While succeeding the iteration, the convergence tolerance is decreased using $1/k$ where k is the iteration number.

The post-optimization initial parameterization decreased stretch, even if it is still over user's assignment. Spectral analysis method will always split charts whose stretch is above user's assignment and guarantees the final result will not contain flip triangles. Instead of general optimization, Zhou et al. (2004) proposed a landmark method in both chartification and parameterization.

Spectral Clustering

The triangular meshes are not always disk-like. We need to partition the surface into a certain number of charts. As a simple truth, the stretch of parameterization declines with the increase of charts number. Recall that global features of a model such as heads, limbs, and tails are related to larger eigenvalues. Zhou et al. (2004) use spectral analysis to find *landmarks* of a model and exploit them to generate charts. This method called *surface spectral clustering is* composed of following steps:

1. Sort the eigenvalues λ_i computed during initial spectral analysis by decreasing order ($\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_N$).
2. Find n which maximizes λ_n/λ_{n+1}
3. For each vertex i, compute its n-dimensional embedding coordinates: $\mathbf{y}_i^j = \sqrt{\lambda_j}\mathbf{v}_j^i (j = 1, 2, \ldots, n)$, where $\mathbf{v}_j$ is the corresponding eigenvector of λ_j
4. Find maximum and minimum coordinate value vertices in each dimension to get totally $2n$ representatives. Remove some of them which are too close to each other, yielding $m \leq 2n$ *landmarks* whose embedding are these representatives.
5. Cluster triangles on the mesh into closest growing charts around m landmarks.



UV Map Generation on Triangular Mesh, Fig. 2 Spectral clustering for a horse model. The vertices with same color are in the same dimension (Zhou et al. 2004)

Use the geodesic distance calculated in previous spectral analysis.

Figure 2 visualizes the spectral clustering method on a horse model. When set $n = 3$, the sum of top three eigenvalues occupy 85% of total energy (energy is proportional to eigenvalue). Therefore, embedded model has homogeneous shape to the origin one and landmarks are located on high frequency surface which means the place has more details.

Boundaries Optimization

The chartification using spectral clustering, however, provides a reasonable partition, brings the issue that boundaries of charts are not smooth, and frequently splits a complete surface into several parts. The ideal chartification has almost invisible chart boundaries that cuts should be distributed on divide between two surfaces with big dihedral angle or the surface with low visibility such as back face of a sofa.

To achieve the reasonable cuts, (Zhou et al. 2004) formulate the optimal boundary problem as a graph cutting problem. Suppose the boundary of two adjacent charts **A** and **B** need to be optimized, the optimization includes following steps:

1. Generate a medial region **C** by expanding a region from the initial split boundary.
2. An undirected flow network graph can be constructed from **C** using an extension of the method in Katz and Tal (2003).
3. Define the capacity $c(f_i, f_j)$ between two adjacent triangles f_i and f_j

$$c\left(f_i,f_j\right) = \alpha c_{ang}\left(f_i,f_j\right) + (1-\alpha)\mathrm{c}_{sig}\left(f_i,f_j\right).$$

The first term corresponds to the objective that cut through edges of high dihedral angle. Katz and Tal (2003) give the formula that $c_{ang}\left(f_i,f_j\right) = \left(1+\frac{d_{ang}\left(f_i,f_j\right)}{avg\left(d_{ang}\right)}\right)-1$,

where angular distance is defined by $1-\cos\alpha_{ij}$.

The second term corresponds to the objective that cut through edges of user's specification. Signals are used to achieve a property of surface, including color, normal vectors, illumination, and visibility. *Integrated metric tensor* (IMT) (Sander et al. 2002) encapsulates how much the signal varies over the surface. Therefore *signal distance* from vertex i to vertex j is given by

$$\sum_k (p_k - q_k)^T M_k (p_k - q_k),$$

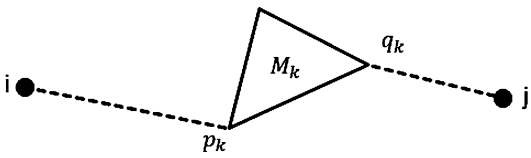
where k is the triangle along the path from i to j and M_k is IMT of the triangle k. p_k and q_k are the signals at end of the path though triangle k, see Fig. 3.

GDD with signal distances, then calculate $c_{sig}(f_i, f_j)$

$$c_{sig}\left(f_i,f_j\right) = \frac{d_{sig}\left(f_i,f_j\right)}{avg\left(d_{sig}\right)}$$

$$d_{sig}\left(f_i,f_j\right) = \left|GDDA(f_i) - GDD_B(f_i)\right| + \left|GDDA(f_i) - GDD_B\left(f_j\right)\right|$$

4. Use graph cut algorithm to achieve new boundary. Zhou et al. (2004) give some boost method to reduce the time consumption.



UV Map Generation on Triangular Mesh, Fig. 3 Signal distance

UV Maps Packing

Atlas-based UV map is the most simple way for users' recreation. Packing parameterized charts into texture space need to fully utilize the area. In Lévy et al. (2002), a Tetris algorithm was introduced. A more simple method is that given the user specified width and height, rescale each chart to make its area in the texture space equal to its area in 3D domain. Then sort them by decreasing area order. For each chart, rotate and put it into UV domain in order to minimize the waste space.

Open Source Tools

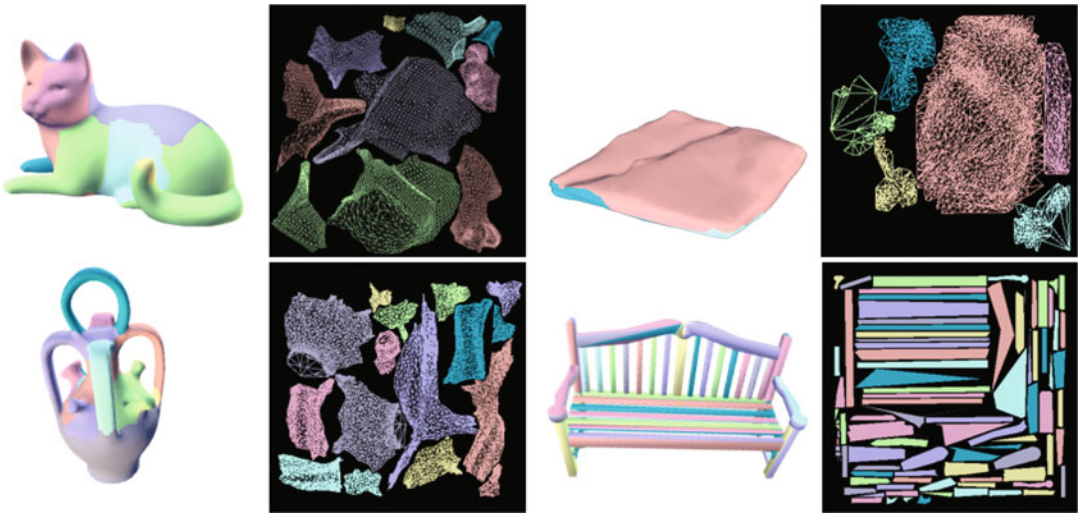
The parameterization algorithm has difficulties on implementation. Many commercial software like Autodesk Maya have built-in tools to generate the UV map. Fortunately, there are some open source projects on Internet so that we can get taste of the algorithm.

UVAtlas (Huang and Walbourn 2014) is a shared library for creating and packing an isochart texture atlas held on Github. It implements the spectral analysis algorithm and an end-to-end UV map generator. Figure 4 shows several results generated by UVAtlas.

Other parameterization algorithms such as ABF++ also have open source projects. Graphite (Lévy 2008) is an experimental 3D modeler, built on top of the Geogram programming library. It has data structures and efficient OpenGL visualization for point sets, meshes (triangles and polygons), volumetric meshes (tetrahedra and hybrid meshes).

Conclusion

UV map generation on triangular mesh is a heavy studied topic in computer graphics. Using open source code like UVAtlas could generate good result with user's specification. This chapter gives a general outline of traditional stretch-driven method, which is an effective pipeline to finish the UV map generation task.



UV Map Generation on Triangular Mesh, Fig. 4 UVAtlas results

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UX

▶ Cognitive Psychology Applied to User Experience in Video Games

UX Design

▶ Cognitive Psychology Applied to User Experience in Video Games

UX, User Experience

▶ The New Age of Procedural Texturing

V

Vection

► Perceptual Illusions and Distortions in Virtual Reality

Vector

► Pipeline of 2D Vector Animation in Television Series

Vector Artwork

► Vector Graphics

Vector Graphics

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Synonyms

Vectors; Vector artwork

Definition

Computer graphics comprised of mathematically derived lines, polygons, and curves.

Description

The term "vector graphics" refers to a method of generating electronic images using mathematical formulae to calculate the start, end, and path of a line. Images of varying complexity can be produced by combining lines into curved and polygonal shapes, resulting in infinitely scalable objects with no loss of definition (Fig. 1).

Vector graphics can be generated via a variety of computational and display technologies, including analog machines using cathode ray tubes. William Higinbotham, for example, famously displayed his 1958 game *Tennis for Two* (Higinbotham 1958) on a repurposed oscilloscope (Fig. 2).

Vector graphics are elemental to computer game history, especially the computer game history of the 1970s and 1980s when the medium was first commercialized. Though arguably less versatile than raster graphics, the wireframes of early vector games such as *Space Wars* (Cinematronics 1977), *Battlezone* (Atari 1980), and *Tac/Scan* (Sega 1982) could be rendered more quickly by their era's hardware, producing more fluidly animated and interactive elements on screen. As a result, it became possible for game

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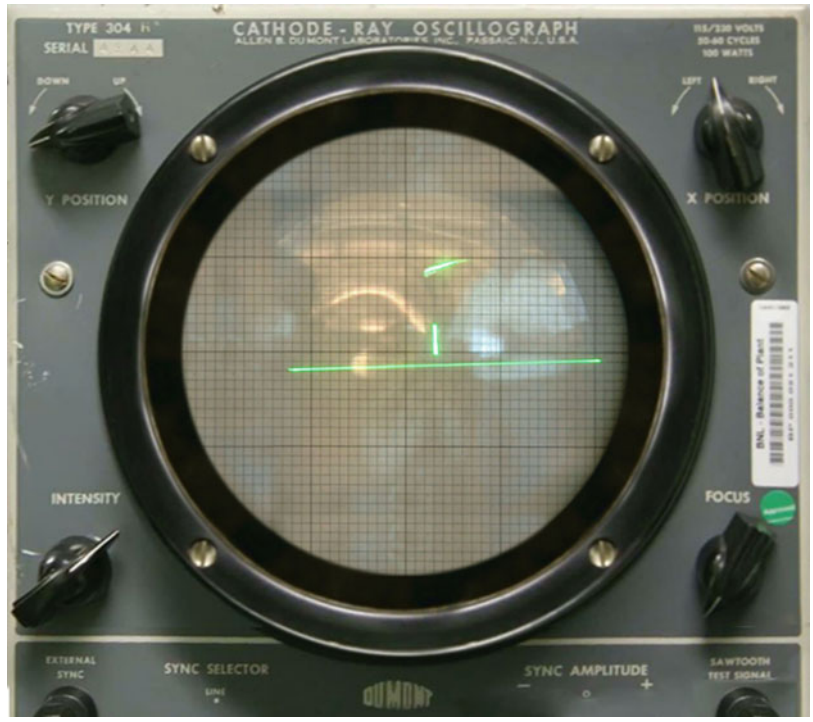
Vector Graphics, Fig. 1 Original image (*left*); magnified raster image (*top right*) versus magnified vector image (*bottom right*) (Image courtesy of the Learning Games Initiative)



Vector Graphics, Fig. 2 William Higinbotham's *Tennis for Two*, an early computer game based on vector graphics (Image in the public domain)

developers to create simple but functional three-dimensional environments, opening the game medium to new designs and immersive possibilities.

Public interest in vector graphics predates the advent of the computer game, however. As early as the mid-1940s, photographs of artfully arranged oscilloscope plots were common in *Popular Science* and other large circulation magazines. In the late 1940s, pioneering electronic artists such as Ben Laposky began to popularize "oscillographic art," and by 1951, scientists and engineers were receiving considerable public attention for their use of cutting-

edge computers such as MIT's Whirlwind, which featured a vectorscope-type graphics display designed to plot the X-Y relationship between two signals rather than the more common display mapping the change of one signal over time.

By the mid-1950s, a vector-based light pen had been created to allow direct user interactions with vector graphics, and in the late 1950s, William Fetter, a commercial artist working for Boeing (and coiner of the term "computer graphics"), began experimenting with vector graphics to better understand the integration of the human body and an aircraft cockpit. Striking for their beautiful representations of the human form – sitting, leaning, and stretching – these figures, which were drawn using an IBM 7094 punch-card system and a Gerber plotter, came to be known as "Boeing Man," and are now considered to be among the first examples of popular computer art. Other companies soon began to experiment with vector graphics in their own ways, including Information International Inc., McDonnell Douglas, General Electric, General Motors, and Bell Labs.

Vector graphics had become sufficiently common by the mid-1960s that Hank Stockert, Norman McLaren, Edward E. Zajak, Mary Ellen Bute, Hy Hirsh, and other artists were able to build careers on manipulated oscilloscope vector signals. Their numerous art exhibits, public lectures, and commercial art portfolios reflected the growing popularity of this emerging visual style. In 1967, only a few years after Ivan Sutherland created *Sketchpad* (Sutherland 1963) – a vector-based drawing program and progenitor of today's CAD/CAM systems – and Doug Englebart built the first computer mouse, digital arts pioneer Charles Csuri created *Hummingbird* (Csuri 1967), a 10-min animation using vector-interpolated 16 mm film. The techniques deployed in this and related cinematic and photographic projects became the foundation for Cranston/Csuri Productions (CCP), one of the world's first computer animation companies (Sito 2013). Yet more than a decade before companies such as CCP began to heavily commercialize vector graphics, Evans & Sutherland – the first computer graphics company – developed a vector-based system equivalent to technology previously only available at high-end military research and development facilities. Two years later – 1970 – William "Boeing Man" Fetter was part of a team that produced an ad for Norelco razors, the first vector-based computer-generated television commercial.

Though the rise of affordable raster technology in the late 1970s blunted research and fine art interest in vectors, the aesthetic remained relatively popular through the 1980s, thanks to coin-operated computer games such as *Asteroids* (Atari 1979) and *Tempest* (Atari 1981), films such as *Return of the Jedi* (20th Century Fox 1983), and music videos such as Mick Jagger's "Hard Woman" (Columbia, 1985). In fact, vectors were even faked in a number of feature-length films (e.g., *Escape from New York* [Avco Embassy Pictures 1981], *Outland* [Warner Bros. 1981], *Inseminoid* [Butcher's Film Service 1981]). Clearly entranced by the vector aesthetic but working with budgets inhospitable to the massive special effects spending necessary to create elaborate computer-generated imagery, filmmakers and other media makers concocted all manner of analog techniques to produce the look of advanced computer graphics without their attendant expense.

Public interest in vector-based graphics during the late 1970s through the 1980s may also be attributed to corporate concentration and conglomeration. Warner Communications' 1976 acquisition of Atari, for example, enmeshed game software and hardware into the sphere of vertically and horizontally integrated transnational media, a convergence that helped translate the specific technical advances of vectors into mass mediated commodities. Warner's production and marketing of vector-infused television, film, and games helped to familiarize and cement the public's appreciation of vector aesthetics and their futuristic significations.

Apart from subsequent periodic fits of cultural nostalgia, the development, use, exploitation, and

imitation of vector graphics in computer games and other media subsided by the late 1980s. Computer hardware, firmware, and software had developed to the point of being able to readily produce sophisticated, smoothly animated, and visually flexible raster graphics. Despite this change, however, vector graphics continue play an important role in computer game development. Many studios, for example, depend heavily on vector graphics to produce visual content for their projects, especially if those projects involve three-dimensional objects. As has always been the case, the generation of numerous concurrent and/or complex vector models tends to be highly resource intensive, and thus game developers now typically rasterize a project's vector graphics once the game build is finalized in order to reduce its computational resource footprint. This relatively simple workflow from vector to raster graphics gives modern day developers the best of both worlds: a highly dynamic development environment that ultimately yields an evocative – and highly efficient – consumer deliverable.

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Vectors

▶ Vector Graphics

Vehicular Ad Hoc Networks

▶ Potential of Augmented Reality for Intelligent Transportation Systems

VFX

▶ Virtual Reality Stereo Post-Conversion After Effects Workflow

VFX, Visual Effects

▶ The New Age of Procedural Texturing

Video Game Culture

▶ Video Game Culture in Cape Town, South Africa

Video Game Culture in Cape Town, South Africa

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Synonyms

Global South; Paranodal play; Regional game studies; Video game culture

Definition

"Video game culture"	New media subculture that has emerged around the global popularity of video games. Scholarly researchers have looked

	at video games from a cultural studies perspective in relation to identity, practice, thinking, learning, gender, children, conflict, and history (Shaw 2010, 1).
"Regional game studies"	Studies which investigate games and gaming cultures "at a range of geocultural scales, identifies connections across and between these scales, highlights and addresses unequal global power relations within gaming culture and within the academic study of games, and enriches the field with new perspectives drawn from regional cultural contexts" (Liboriussen and Martin 2016).
"Paranodal Play"	play practices that are "un-networked, offline and untrackable" (Pallitt et al. 2019.
"Global South"	An situational term coined by Walter Mignolo in his essay "The Global South and the World Dis/Order" (Mignolo 2011) to describe countries which were on the receiving end of globalization and colonialism, and still endure the effects of colonialism to this day.

Introduction

"Game culture" is most frequently defined through descriptions of gamers and their collective practices and identities (Shaw 2010). As elsewhere in the world, gaming is a ubiquitous practice in Cape Town, South Africa. Young people play games on consoles, PC's, and mobile devices. They do so at home, on the move, in arcades, cybercafes, and libraries (Pallitt et al. 2019). Yet income inequalities greatly influence consumption patterns and, in turn, shape gamers' experiences of digital games (Walton and Pallitt 2012).

Early South African research into gaming reported computer game development projects (Amory et al. 1999), scripting environments (Elliot et al. 2009), and the use of games in, for example, mobile maths tutoring (Butgereit 2007). A small body of studies from Cape Town are beginning to address the significance of gaming in children and young South Africans' everyday lives (Pallitt et al. 2019).

Studies of video game culture in contexts of the global South have shown that there are great regional differences in gamers' experiences of games and their subsequent gaming cultures, related to content, context, and infrastructure (Penix-Tadse 2019). In Cape Town, differential access to infrastructure for gaming can be observed at three different scales: participation in mainstream global gaming culture, participation in "indie" gaming culture, and the cultures of "paranodal" (Mejias 2013) games communities who are less easily documented.

Mainstream Video Game Culture

Vizeum's Consumer Connection Survey estimates that around 11.4 million people play games on consoles in South Africa, while 5.8 million play mobile games (Hall et al. 2017). *Grand Theft Auto V* and *Fifa 20* are the best-selling titles for PlayStation and Xbox consoles in 2019 (Prior 2019), while *Dream League Soccer 2020* and *Real Commando Secret Mission* (*Free shooting games*) topped the lists for mobile devices (SimilarWeb 2020).

Cape Town hosts a number of expos and fan conventions to cater to this vast community of gamers. *Afresports*, *Ucon*, *ComicEx*, *FanCon*, *EGE,* and the *Canal Walk gaming expo* are all based in Cape Town and cater to "gamer and geek culture" (Dredd 2019) in the city. These mainstream events focus on AAA games titles, e-sports, and Local Area Network (LAN) competitions.

Skotnes-Brown has argued that the legacies of colonialism have greatly influenced video game culture. For example, she has shown how the local chapters of the *Dota 2* community, the multiplayer online battle arena game (MOBA), are riddled with toxic and racist behaviors (Skotnes-Brown 2019). Skotnes-Brown has argued that this reflect a broader structural problem associated with "hardcore" gaming – largely considered a white

male hobby – where racist attitudes emerge in "safe spaces" provided by online anonymity.

Nevertheless, in 2016, the measurable mainstream popularity of video games drew the attention of government bodies such as the department of Economic Development and Tourism (DEDAT) and industry associations such as Cape Innovation and Technology Initiative (CiTi), Interactive Entertainment South Africa (IESA), and the Cape Craft and Design Institute (CCDI) to motivate for the potential of Serious Games to "address prevalent social challenges throughout South Africa, and particularly the Western Cape" (Hall et al. 2017, 1). In a "State of Gaming Report" from 2017, Hall et al. argue that serious games can be applied locally to tackle social problems, advance research in science and technology, advance innovation, supplement education, and advance medical therapies Hall et al. 2017, 6–7). In order to harness this power, these organizations launched the "Serious About Games" initiative, which invited local indie developers to pitch serious games concepts in collaboration with local NGO's (Serious About Games 2016).

Indie Video Game Culture

"Indie gaming," and particularly concepts of "indie game culture" (Simon 2013), changes our scale of focus to the production, in addition to the playing, of games. Simon argues that the term "indie" forces scholars of games to shift our analytic attention to the provenance of the game – those who made it and the conditions under which the games were made and distributed: "to speak of indie games is not to speak only of the games themselves or of the experiences of gameplay but rather of the cultures of game development from whence they came" (Simon 2013, 2).

In South Africa, a central pillar of video game culture is embodied by Cape Town-based independent organization "Make Games South Africa" (MGSA) – an association that supports and connects local game developers through forums and monthly meet-ups. MGSA can be seen as a "cultural intermediary" in promoting and supporting indie game development (Parker et al. 2018), connecting developers with collaborators, funding and distribution opportunities (Hall et al. 2017). As of 2017, there are 15 full-time games studios in the city of Cape Town (Hall et al. 2017, 9). With many more freelance or hobbyist game developers creating games in the city, games such as *BroForce (Free Lives), Desktop Dungeons (QCF design),* and *Genital Jousting (Free Lives)* have been developed in Cape Town, winning numerous awards and accolades.

Beyond the online forums and monthly meet-ups, indie game developers in Cape Town meet up at "game jams" – events where game developers as well as novices can collaborate on creating new games or game prototypes in a time-constrained environment (typically 48 h) (Preston et al. 2012). Members of MGSA host physical locations for major annual international game jams such as the *Global Game Jam* and *Ludum Dare*. In terms of local initiatives, the *South African Game Jam* is hosted by *Free Lives* (a studio based in Cape Town).

In term of exhibitions, indie game developers are able to display their work at the *Super Friendship Arcade* (*https://www.facebook.com/superfriendshiparcade/*) – a sporadic pop-up exhibition of games and hardware made by the community, and at a more professional level, at the annual *Playtopia* Festival (*https://www.playtopia.co.za/*), which is held every December since 2018 at the Castle of Good Hope. These events also host their own jams to create content for their playful media exhibitions.

Paranodal Video Game Culture

Beyond the scale of main stream and indie culture, many gamers in the city of Cape Town experience games in a way that is "paranodal" (Mejias 2013) – at the margins or completely outside of digital networks. Many of these gaming practices emerge as part of a broader phenomenon of "pavement internet" (Walton 2014) where information (including digital goods such as images as games) downloaded from the web trickle down through interpersonal networks at low data costs. For many of the city's poorest residents, games are only an option if they are either free or very low cost. That does not mean that these cultures are

not thriving. Frequently these practices go unregistered on the network. For example, gaming that happens in public access venues such a libraries and cybercafe's, on mobile devices where games have been cloned by Wifi-Direct sharing applications such as *ShareIt,* and on older modified consoles with pirated games (Pallitt et al. 2019).

In Cape Town libraries, as in many similar sites globally, public access computers were first appropriated by young people, particularly young men and boys. These groups were attracted to the venues at least in part because of their interest in games (Valentine 2004). Early evaluations of the provision of internet access (known as the "SmartCape" project) pointed to the ways groups of boys and young men monopolized the facilities, congregating around computers for long periods (Sooful et al. 2002). Valentine (2004) reports that libraries responded to these early adopters in two ways. On the one hand, they made use of the collective know-how of informal experts by encouraging "volunteers" who helped others use computers and sometimes informally and unofficially charged small fees for doing so. On the other hand, the City libraries imposed time-limits and other restrictions on computer use. Library members were allowed to use the computers for any activity of their choice, barring the use of pornography, but they were restricted to short periods of time (usually between 20 and 60 min, depending on the demand and available facilities). Physically the library spaces and software system were configured to support silent individual reading or research with computers rather than embodied social play or the use of mobiles (Walton and Donner 2012).

Acknowledging young people's abiding interest in gaming, the Central Library was redesigned and now provides a specialized basement area set aside for children's books, where young people enjoy exclusive access to dedicated computers. These machines are often used for playing Flash-based internet games (Pallitt et al. 2019).

Another specialized gaming facility in Cape Town exists in Harare library, which was built as part of a project of urban upgrading of the Harare informal settlement area in Khayelitsha (Pallitt et al. 2019), with the overall intent of preventing violence in the area (Pallitt et al. 2019). Here a separate room is provided for gaming on computers and a Nintendo Wii console.

While there are few studies that explore gaming in domestic spaces within Cape Town, a handful of studies have pointed at the appropriation of video games as childcare in low-income areas such as Ocean View (Venter 2012) among children between the ages of nine and seventeen. Here households were not connected to the internet, and thus console gaming could only happen offline. Mobile devices, too, were intentionally disconnected to save on data costs.

Instead, young people invented their own digital games. For example, images of celebrities or other interests were collected or traded via Bluetooth in "swapping games," where mobile photo albums become a digital incarnation of the playground sticker album. Children would negotiate the relative value of images among one another: certain images were deemed more "expensive" owing to the data costs incurred to obtain them. These exchanges were largely gendered – with boys typically exchanging images of cars and girls exchanging images of celebrities (Pallitt et al. 2019).

Conclusion

A review of known video game cultures in Cape Town, South Africa, show diverse identities and practices tied to participation in gaming communities. This entry has highlighted three scales from which to observe culture within this context: mainstream, indie, and paranodal. These divergent cultures are influenced by video game content, context, and available infrastructures for play.

V

Cross-References

- ▶ Challenge-Based Learning in a Serious Global Game
- ▶ Children's Games, from Turtle to Squirtle
- ▶ Gamification and Serious Games

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Video Game Music Middleware

▶ Adaptive Music

Video Game Narrative

▶ Narrative in Video Games

Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation

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Synonyms

Game writing; Narrative; Narrative design; Storytelling

Definitions

Narrative is a fictional universe made up a mythology of characters and settings bolstered by a story (but often a series of stories), theme, and tone.

Introduction

Budget constraints in game development often dictate the primacy of silent, visual storytelling. This entry will identify and describe the four most critical elements of said storytelling.

Overview

Alfred Hitchcock once said, "If it's a good movie, the sound could go off and the audience would still have a perfectly clear idea of what was going on." In video games, where narrative is often a secondary consideration or an after-thought to gameplay, Mr. Hitchcock's words should not only be heeded, but they should serve as primary goal for narrative designers and game writers alike.

Why though? Shouldn't the narrative be at the forefront of every gamer's attention? It should, but industry reality dictates otherwise. The typical and historical methods of unleashing story have required the use of cut scenes or cinematics, which are often met with disdain by gamers who do not want their gaming experience to be interrupted. Game developers are not necessarily the biggest fans of cinematics either, as they can be very expensive to make.

In-game narrative, such as walking through an environment while a character is talking to the player, is a semi-popular method to communicate story, but absorbing the details from characters' dialogue can often be a challenge when a gamer is focused on surviving, shooting, hacking-and-slashing, grinding, or traversing.

There are many tools in the arsenal of a writer to reveal story or at least "drip-feed" segments of it. But narrative designers cannot always rely on the conventions of cinema storytelling to tell the story of a game. There are, instead, the universal fundamentals of visual storytelling to which to turn. It is here where story silently wields its powers and infiltrates the minds of gamers without their knowing it. In fact, if one asked them what the game is about, gamers would do so handily. But if one asked them what the *story* is about, gamers often would fail to do so, even though it would probably be identical to how they would describe the game.

This is because people – no matter what walk of life from whence they came – associate story with only what is spoken or what is visually written. What they do not realize is that story can be more than that. In fact, it does not always need words communicated to an audience. (It needs words from writers communicated to designers and programmers to build, however!) The motion picture – in this case, a screen experience that progresses with a camera, either directed by a player if a game or a filmmaker if cinema – communicates so much more than words do, due to its wide visual canvas that expands with every movement of the camera.

Make no mistake: words do add more to a story experience. But there are some basics that, if missing, render a story anemic.

Setting

Setting is the simplest, most basic building block of story. Where characters find themselves is sometimes as important as the characters themselves. Because it is in these environments in which action takes place.

But action, in this context, does not refer to blowing up buildings or killing an alien species. These instances are, instead, activities.

Action, in the dramatic sense, refers to tension or conflict. And instances that explain, diffuse, or enhance tension are action. Therefore, a setting works in lock-step with action because it is these new environments in which tension rises, either through the introduction of: new characters; new difficult topography that must be traveled; or pieces of a goal or mystery that must be solved/discovered before a player can move forward.

Inherent to setting, however, are silent qualities that cue certain psychological responses. A desolate planet, for instance, communicates a sense of menace and isolation. A battlefield

communicates immediate stress, allegiances, and dogged need for survival. A city communicates lack of space or quietude, obstacles by way of bystanders, and faster pace.

It is possible that, through years of association with these environments through other media, one's instant take on them is less inherent than it is learned. Nonetheless, they carry with them certain expectations that inform a player's experience.

Power Status

Silent storytelling fails to do its job if it cannot reveal the power status of its characters through visuals. When one sees these characters for the first time, he/she often carries psychological prejudgments that compel him/her to view a character a certain way. More often than not, game developers (and cinema professionals) feed into these preconceptions. Archetypes have endured for a reason; one cannot purge from his/her collective unconscious basic, primitive physical markers.

A tall, athletically built man with a full head of hair communicates strength, leadership, and heroism no matter how outdated and unfair that notion is these days. Nathan Drake (*Uncharted* series) and Thor still sell millions of game copies and garner high box office.

Link, the legendary hero from the *Zelda* franchise, is not an exception despite his physically unimposing stature. His adventures are almost always solitary; therefore, there is no one in his immediate environment to compare him to. Indeed, facing off against a Goliath-character type happens to him all the time, but the same thing happens with Indiana Jones, Han Solo, and Nathan Drake – eventually, a hero will confront someone bigger than they are. Visually, this communicates an underdog situation and highlights the immediate life-or-death stakes of the confrontation.

A great example of visual power status comes from another medium. *Broadway Danny Rose* is an underrated classic from Woody Allen. As a D-level talent agent who represents F-level talent, Danny Rose has no respect in the entertainment world. A man of short stature, it is a wonder how he survives financially when each of his acts are nothing short of a hot mess. One day, Danny finds himself in a conundrum as he must protect his most coveted act, a washed-up singer name Lou Canova, and cover up Lou's affair with his latest mistress, Tina Vitale. Lou's career is somewhat being resurrected, and if his wife finds out he is in love with another woman, it will set him back irrevocably. Danny must secure safe passage for Tina and Lou to meet up during a big performance at Carnegie Hall. Alas, this is no small feat, as Tina, insulted by Lou's inability to break things off with his wife, wants nothing to do with him. Danny is nonetheless persistent, convinces her to reconsider for Lou's big performance, and then guides her through a series of misfortunate events (some involving the Mafia) that result in Danny and Tina falling in love. But nothing is spoken between the two about this love. When the adventure ends, Lou flourishes during his comeback moment and Tina rediscovers her affection for the once washed-up star. To pour salt on a wound, Lou then breaks off his relationship with Danny after a bigger agent poaches him.

During Thanksgiving, Danny hosts a party for his F-level clients: a stuttering ventriloquist; a glass harpist; an animal balloon maker; and others. If one pays closes attention, he/she will see that Danny is the tallest of the bunch. (The exception being an awkward spectacled comedian who sits for the majority of time during Danny's moment of adoration from his clients.) Among the Lilliputians, Danny is Gulliver. The dialogue is irrelevant; it is the visual that counts here. All the failed acts look up to their king who has the most power in a powerless world.

Tina then knocks on his door and apologizes. Danny rebuffs her and returns to celebrate with his clients. After a moment, he rushes out and finds her a block away. He reaches out for her as a gesture to return to his apartment. She follows. As they exit the frame, the camera stays on the Carnegie Deli, the setting where the film began. This distant shot captures the most romantic of gestures. Voice over is in the background. It is inconsequential; in fact, it is just noise. The reversal of Danny's power solidified. The visual says it all.

This is environmental storytelling at its finest. Power status defined at its purest level.

Tone

As briefly stated in the "Setting" section, there are certain visuals that, either through an inherent or learned association, communicate an instant psychological response. Most, if not all, of these responses are connected to tone.

An abandoned, dark subway station – as in *The Condemned II: Bloodshot* (Monolith 2008) – plays off of one's fear of the unknown. What will jump out at me at any given moment? Again – no words need to be uttered through voice over or written on screen. This environment alone shapes a player's tendencies toward fright and builds suspense.

An early 1900s dystopia filled with American naivete and hope is quickly undermined when blood paints the streets after a Pinkerton detective crosses paths with pseudo-Christian, America First zealots. *Bioshock: Infinite* (Irrational Games 2012) consistently challenges a player's sense of status quo and peace when the aerial nation-state of Columbia is gradually revealed to be a cover for White Supremacy. Everything that is pretty and peaceful is a lie. That juxtaposition of opposites communicates a tonal disconnect that is unnerving and disorienting.

Perhaps there is something inherent in the way a person processes these environments. A dark, abandoned, rotting subway station vs. a colorful, well-designed, harmonious utopia. One is immediate about its intentions to frighten; the other waits a little bit longer before revealing the moral rot underneath. In either case, the tone speaks volumes in terms of story. It sets player expectations and then either doubles down on them or evolves them only to surprise a player through a greater sense of dread and menace.

Escalation

Story often involves a seminal question: "What happens next?" These series of occurrences, however, need to be aligned with a character's emotional journey. So, if events can escalate higher and higher and there is no psychological growth of the character, then escalation is irrelevant. Aristotle's *Poetics* and Joseph Campbell's *The Power of Myth* are excellent sources of defining "plot points" or story milestones. Each work articulates a strong sense of what a character's ultimate journey should entail. Among them: recognition, reversal, catharsis (Aristotle); Call to Adventure, Refusal, and Resurrection (Campbell).

With some permutation of these concepts, a game story is often successfully weaved. Again, escalation of these is key. And again, these events can communicate story without audio or text. (A great example of this occurs in the game *Journey*, as I will explore later.)

Goals are often easily communicated through visuals alone. If one raids the beaches of Normandy and is immediately attacked, his/her immediate goal is to get out of harm's way and, most likely, kill the enemies ahead so that the attacks can stop, allowing the player to usurp the territory from the opposition.

Up ahead, there maybe a beacon or coms center that looks valuable somehow. What is inside? Either it sticks out because there is nothing like it in the territory one finds him/herself in, or its mysteriousness is too compelling to avoid. This is a medium goal.

A long-term goal will be revealed gradually, as a player progresses from one medium goal to the next. (Conquering a massive territory or prevailing over a campaign, for instance.) What the player experiences is a steady progression of hardship – or *escalating burdens* – that she/he must overcome in order to continue on. One's moving ahead amidst these circumstances shows escalation.

Why not stay put? Games do not work that way. They require moving forward in every component of design at all times. But the context and tapestry that are wrapped around these goals open the doors for more storytelling. This is part of the core progression of a game. How one fulfills this progression often requires the efforts of a writer or narrative designer to fill in what is happening in between these goals.

Again, assuming the sound is off and there is no UI text to inform a player of what is going on, a writer must identify with a game designer: (a) what the environments are ahead; (b) the sequence of events as a player travels from one

environment to the next; (c) and what happens within these sequences.

The result is story.

How These Parts Work Together

There is no better example of silent storytelling than (thatgamecompany 2012).

From the moment the game starts, a player is immediately thrust into a desolate world, a desert filled with tombstones. One wonders what happened here? And since tombstones carry with it the association of death, one must wonder whether or not that is a fate our protagonist will confront further on in the game.

Setting: Desert. Tombstones abound.

Tone: Serene yet menacing. Bright yet mysterious.

Power Status: Unknown, as the protagonist is the only one here. Unless he/she is a character that contends with the elements of the earth; in which case the protagonist is an underdog compared to the breadth of his/her surroundings.

Escalation: There is an indiscernible structure up ahead. The player has no choice but to head toward it, unless he/she wants to get lost in the vast desert filled with nothing but sand. When the player reaches the structure, he/she is empowered by a rock with a light helix that spirals from it and fleetingly envelopes the player. Immediate goal and power-up achieved.

All of this in the first 4 min of the game! Again, no words are spoken or written on screen. Yet the goals are clear, the tone is palpable, and the setting is all-encompassing. It is the power status that remains a mystery, but again, enough visual stimuli have been presented to the player where contending with the environment compromises his/her power or leaves him/her reliant upon it. In which case . . . omnipotent, the protagonist is not.

From time to time, the protagonist will encounter mysterious tall, caped figures who endow our hero with a piece of a hieroglyphic or ancient pictogram that reveals the planet's past (or possibly the player's future) in the form of a primitive, yet dynamic map. The more encounters one has with this figure, the more the map is filled out. What is more, each encounter is followed by an unlocking of a new path or chapter upon which our hero embarks.

For the first half of the game, the desert environment is pretty uniform. But then the world turns dark and soon our hero is being hunted by a floating predator that is a cross between a centipede and a frilled shark. Much later on, after the hieroglyphic becomes complete and our hero's fate is revealed, he/she must traverse up a mountain in the midst of a windy tundra. The stakes are clear: survival. And reaching the top is the presumed safe haven.

The ending is nothing short of a tragedy wrapped, ironically, in beautiful imagery. The music, while not accompanied by words, does not deliver the aforementioned elements of storytelling; nonetheless, it adds an extra layer of magic that galvanizes numerous emotional hot spots.

There is not one moment where a player does not know where they need to go, what the stakes are, what their relationship is to the environment is, and what the feeling of the world is conveying. *Journey* leverages all of the visual tools that its environment can organically convey and is, thus, a masterpiece in silent, visual storytelling.

Conclusion

Setting, tone, escalation, and power status are clearly not the only pillars of storytelling in games. Dialogue, structure, plot, and theme are important as well. But games do not often produce the full narrative package when the final product is released. It is not ideal when this happens, but it is common.

It is often the case that a narrative falls apart when the bare minimum (i.e., setting, tone, escalation, and power status) is missing or improperly defined. Simply put: structure, plot, dialogue, and theme are sufficient but not necessary for game narrative. But tone, setting, escalation, and power status are both sufficient and necessary.

And they are, mainly because a game's budget is always under scrutiny. When cuts and reductions are a result of said scrutiny, the typical targets include voice-over (a vehicle for

dialogue) and cinematics (a vehicle for structure and plot).

When a writer is hamstrung with such a limited storytelling arsenal, it is incumbent upon him or her to assure that setting, tone, escalation, and power status are injected into the narrative and at their highest level of quality at any given moment.

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Video Game Trolls and Dopamine Withdrawal

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Synonyms

Dopamine; Troll; Trolling

Definitions

Dopamine is a chemical compound that is released in the brain to send signals to other nerve cells, including those that make possible reward- or pleasure-driven behavior. Trolls are Internet users who stalk, degrade, diminish, or abuse individual people, brands, or institutions through Internet channels including email, social media websites, and/or blogs. The act of trolling is to apply these toxic actions through said Internet channels.

Introduction

Online trolling has become a shameful practice since the early days of the Internet. However, in recent years, the actions of trolls have reached new lows that go beyond petty insults on Twitter. This article raises an unexplored possibility as to why trolls have become so excessive and extreme in their hostility.

Overview

Trolling is an unfortunate yet persistent part of Internet culture and has reared its ugly head since the early days of online service provider chat rooms and message boards. What makes the digital hostility so pervasive and effective is the Internet's anonymity. Hate is hidden behind a faceless alias, the recipe for troll prosperity. If authenticated and transparent identities were required when engaging in across-the-board online discourse, Internet etiquette would be vastly different than it is today. It would not be weaponized, or as weaponized.

Online is also an environment with a like-minded multiplication effect. One can always find other trolls who share the same opinion as he/she has and can be easily corralled to deluge someone outside their echo chamber with relentless, vicious comments.

But trolling has gone beyond the endless stream of insults on Reddit or YouTube

comments. It now involves destroying someone's reputation, livelihood, privacy, and security.

In the summer of 2014, gaming professionals like Zoe Quinn, Anita Sarkeesian, and Brianna Wu were targets of relentless harassment by gamers who took umbrage to their political views and phantom privileges. The controversy was soon to be called #GamerGate. It started after people in the gaming world ran with a rumor that Zoe Quinn had an affair with a video game journalist to gain unfair advantage (read: positive game reviews) in the industry. But the rumor was based on fiction and started by Quinn's spurned ex-boyfriend. When the truth surfaced, however, it was too late. Quinn was a target of relentless online sexist harassment, privacy violations, and death threats. Those who had mocked the harassers or defended Quinn (like Wu and Sarkeesian) quickly became targets of an aggressive, harassment campaign as well.

To this day, the flames of the controversy have not fully died out. In the spring of 2017, the cross hairs were on Allie Rose-Marie Leost, an animator on *Mass Effect: Andromeda*, who was digitally assaulted by outraged gamers for the title's perceived decline in facial animation quality. Leost was easy to identify as she listed her role on Twitter – the same platform where she subsequently received an endless stream of misogynistic vitriol. But there are other animators responsible for *Andromeda* as well, all of whom are listed on the game's credits and many of whom have Twitter accounts. Yet they were not targeted. Why Leost? Even if she were the sole employee responsible for its facial animation, does she deserve such hateful obloquy? Alas, the misogynistic legacy of #GamerGate lives on.

Why does such vicious trolling get so out of hand? Attacks on gender, sexuality, race, and religion are the inexcusable, yet common fallback for the ignorant. When trolls can neither get their way nor persuade others successfully, a quick epithet against an enemy's identity is expected.

Today, unfortunately, there are more weapons at the disposal of the ignorant. Now it is easy to gather a posse to: overwhelm Amazon, lower a game's ratings, and detrimentally affect sales; hack into one's email account and post his/her social security number or physical address on Reddit; poison one's social media reputation by posting excessive negative comments about one's work and thereby making one radioactive to prospective clients or employers; amplify attacks on all social channels and emails and flood the victim with hatred from thousands of like-minded trolls. Such great lengths to hurt someone obviously go beyond the pale of social acceptability or rationality. These actions are cartoonish, yet they are real and not isolated incidents.

To understand the depths of this commitment to hate is to understand the emotional impulses that drive someone to do such things. Is it the type of person who's attracted to trolling, or is there something that is brought out from them when he/she feels threatened? The answer could be found within addiction.

Gaming and social media are related in the sense that there are built-in mechanisms to the interactive experience that lock in one's long-term, repeat usage. These mechanisms, such as a Facebook "like" or the killing of a Nazi Zombie in a video game, are instant gratifiers and yield a dopamine release upon every tap on the screen or press of the X button. This dopamine release encourages the repetition of that act, which, in turn, increases more dopamine levels. Hence, the cycle of addiction is born, developed, perfected, and repeated.

Dopamine is the neurotransmitter that controls the brain's pleasure center. But, if dopamine is constantly being triggered during these interactions, what happens when one stops playing games or using social media? Is there withdrawal?

Consider gambling, which does not involve the ingestion of chemicals like drugs or alcohol to induce addiction (Yet, it is considered a significant addiction and is, thus, now included in the *Diagnostic and Statistical Manual of Mental Disorders* (DSM).) A 2013 *Scientific American* article expanded the definition of traditional gambling addicts to include online gamblers as well.

That same article described what happens when gamblers are in withdrawal:

> . . . they feel physically ill, cannot sleep and shake uncontrollably – if their brain is deprived of a dopamine-stimulating substance for too long. At

the same time, neural pathways connecting the reward circuit to the prefrontal cortex weaken. Resting just above and behind the eyes, the prefrontal cortex helps people tame impulses.

In essence, gambling addicts will experience a loss of impulses once they are in withdrawal. The behavior of #GamerGate perpetrators is very much in line with the results of a loss of impulses too. Consider their:

- Using incessant profanity in social media to demean a person's gender, race, or sexuality
- Launching a targeted stream of harassing emails and social posts that occur many times a day, several days a week, for weeks to come
- Recruiting others to gang up on a victim
- Posting private data of a victim to intimidate him/her
- Encouraging people to stalk or cause physical harm to the victim
- Exacting a similar harassment campaign against a victim's loved one or relative(s)

Evil is evil, and there is no excuse for such reprehensible behavior. But it will take unconventional means to reduce the collective behavior's effect, volume, and acceleration of abuse. Right now, there is no algorithm that can fix this issue. And the web is far from being censored. But if the mental health community were to get involved in this arena, it is possible to effect positive change. Questions to answer:

If these trolls are going through interactive withdrawal when they target a victim, how can we alter the ways games and social media sites are designed?

Moreover, is the answer to taming trolls the same as it is when treating addiction? Or does the addiction never get noticed because of the ability to be anonymous on Reddit, 4chan, Twitter, etc.?

Is there a dopamine release when a troll receives an "upvote," "heart," or "like?" If so, are interactive environments, by nature, outlets for aggressive behavior for some people, even if the interactive environment is not a first-person shooter or a hack-n-slash video game? If this is the case, then how do we change the stimuli that feeds trolls so that players or social media users can experience the same fun, but the aggression does not linger on?

Conclusion

This article is not an exploration of the science behind addiction of the brain of a gamer or netizen. It is, instead, a call to action for mental health professionals to make this phenomenon a priority, so that the online community can eventually prevent trolling victimization more effectively and purge the toxic environment that has poisoned online discourse for far too long.

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Video Games and Accessibility: A Case Study of The Last of Us II

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Synonyms

Accessibility in Games

Definition

Accessibility in Games: The practice of making your games playable by gamers with disabilities. This practice also serves gamers with context-dependent access issues such as slow network connections, playing in over- or underlighted environments, playing in loud environments, language barriers, temporary injuries, etc.

Introduction

With such a wide variety of genres and platforms, video games are often branded as having something for everyone (Newman 2013). At face value, this is accurate; however, when we take a closer look at accessibility, this is not always true. As Zahand (2018) puts it: "For most of the games industry, accessibility in video games is a low priority. One reason is because of a lack of awareness among developers about accessibility issues-developers who are not disabled might not be aware of the ways that they can make a title more accessible to people with disabilities or impairments."

The gaming community has not always been kind to those with vision and mobility problems (Yuan 2009), and often people have found a need to create expensive custom controllers for loved ones that struggle with fine motor skills (Bierre et al. 2005). Issues like these often go unconsidered, but some games, like *The Last of Us Part II* (developed by *Naughty Dog* and released by *Sony Interactive Entertainment* on June 19, 2020), are making larger strides to bring more options to the table without affecting gameplay.

A Brief Summary of Hardware and Software Accessibility

It is no secret that video games are becoming a large part of everyday life (Egenfeldt-Nielsen et al. 2019). The constantly growing industry provides a major way to connect with friends and strangers alike. Games can provide educational benefits, improve motor skills and reaction time, and more. However, while games can provide a vast number of benefits, they have not been exempted from societal critique. As society grows and changes, we are finding a larger need for diversity and inclusion. Often this conversation steers toward adding more women and people of color to video games and development teams, which is a very important conversation, but those with disabilities are still lacking major inclusion. There are more than 33 million gamers with disabilities just in the United States (Mut 2019). Despite this, software and hardware for people with disabilities has not been in focus for major game developers, at least not until very recently.

Over the years, there have been major attempts to modify controller design. Some controllers have improved on design, but some have just

been totally awkward on confusing. The Nintendo 64 controller, for example, is often remembered as being bulky and strange. The Xbox controller is often cited as being noninclusive because of how large and difficult to hold it has been (in contrast to the Xbox Adaptive Controller, a controller that is designed for gamers with disabilities; Stuart 2018). Some controllers have even been created for such a specific game or purpose that they are basically useless outside of their one purpose – like the Wii bowling ball. With such a large variety of controllers, one would think that finding a controller adapted for disabilities would be easy. However, when attempting to shop online for accessibility controllers, basically only one option comes up. It is specifically for the Xbox One, and it costs around $100. This seems to be a great option and major start for companies like Microsoft, but there is definitely room to improve and keep growing. There are a few other options for controllers, but none of them are on a large production level; most are player lead initiatives either hacking or modding controllers to assist their fellow gamers (some examples can be seen at Edwards 2019). This is problematic considering not everyone has the needed fine motor skills or hand function to accurately use the typical gaming controller, nor do they have the time and money to seek out elaborate custom controllers. There is certainly a market for these types of products, but it just has not been a priority for major studios. There are some studios, however, that are working to integrate accessibility into their game software to make up for a lack of hardware. In contrast to hardware options, software accessibility has made major leaps and bounds throughout the years, and not just players with disabilities are taking advantage. Subtitles are a simple, yet major option used by so many players, and up to one-third of players used one-handed settings featured in *Uncharted 4* (Stoner 2020).

The Last of Us Part II: The Most Accessible Game So Far?

Naughty Dog, the developers of *Uncharted 4*, have seen the use and need for accessibility in their games and have worked to make major developments in this area. Their most recent game, *The Last of Us Part II*, has many critics citing it as perhaps the most accessible game of all time (Molloy and Carter 2020). There are over 60 accessibility presets in the game alone as well as full control customization. According to the game's page on the official PlayStation website, the game's accessibility features are grouped under 3 main categories: vision accessibility, hearing accessibility, and motor accessibility ("Accessibility Options. . ."). The first category, vision, gives players the options of text-to-speech, high-contrast display, HUD scale, auto-targeting, traversal and combat audio cues, navigation and traversal assistance, ledge guard, enhanced listen mode, unlimited invisibility while prone, and skip puzzle option. This preset, "configures all the recommended settings designed for players who are blind or have low vision." The second preset, hearing, adds several indicators for picking up items, dodging, and awareness as well as more subtitle options and vibration cues. The complete list of these options is as follows: awareness indicators, pick-up notifications, frequent dodge prompts, subtitles, subtitle names, subtitle directions, combat variation cues, and guitar vibration cues. The hearing accessibility, "configures all the recommended settings designed for players who are deaf or hard of hearing." The last preset, for motor accessibility, adds auto-targeting, auto weapon swap, auto pick up, camera assist, navigation and traversal assistance, ledge guard, infinite breath, repeated button press, melee combos, weapon sway, and skip puzzle option. This preset, "configures all the recommended settings designed for players with a physical or mobility disability." Each preset is adjustable and made to work with each other if needed. The game also provides a one-handed mode and fully customizable controls and button mapping that work with these features as well. Additionally, more in-game features tackle other issues like magnification, motion sickness, and navigation, to name a few.

In response to The Last of Us Part II's accessibility options, one player with vision impairment broke down in tears after years of wishing for game features like the ones mentioned (Acovino

2020) which made its way into major news outlets. With so many options and considerations put into the game, it may seem like this was a huge challenge to develop. However, Takahashi (2020) points out that "Naughty Dog thanked about seven people for helping them with the design [. . .] that means it isn't a huge economic burden to think about these kinds of things."

Various previous research suggest that working with local or relevant communities can overcome many inclusive design issues in video games and other virtual environments (Mangiron et al. 2014; Bierre et al. 2005; Jahanian et al. 2018; Şengün et al. 2019; Aguado-Delgado et al. 2020). Naughty Dog is proving that it is not hard to consider their players and put in effort for everyone to enjoy their games. Moving forward, game developers should increasingly include options like these in their games, and when they do, these efforts are seemingly appreciated by the gamer communities.

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Videogame Engagement: Psychological Frameworks

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Synonyms

Absorption; Enjoyment; Gratification; Immersion; Motivation

Definition

Answering the questions of how and why people engage with videogames or why they enjoy certain videogames more than the others has been a perennial effort in videogame studies. On the one hand, designers and developers strive to discover novel ways to make videogames more enjoyable, immersive, and gratifying. On the other hand, researchers mobilize gameplay data to cluster players into categories depending on how they engage with videogame content and explain their behavior types. One prevalent resource to explain videogame engagement behavior has been the adaptation of previous psychological theories and frameworks to the field (Boyle et al. 2012; Şengün 2016; Balkaya and Catak 2016). Typically, these theories and frameworks were developed for non-game contexts (e.g., sports, job performance, self-motivation, technology use, economic behavior, risk-taking, etc.), and they are accompanied by a readily available rich literature. In this article, several of the most-cited and most-adapted psychological theories are summarized and discussed. Although various other frameworks and player typologies emerged with contemporary videogame research and gameplay data (e.g., Bartle's player types, 1996; 2004; Lazzaro's gaming emotions, 2004; Sherry et al.'s play motivations, 2006; etc.), here specific focus is given to the psychological frameworks developed for non-game contexts first and adapted into the field later.

Introduction

Boyle et al. (2012) performed a systematic review of research on videogame engagement published between the years of 1961 and 2011. They uncovered fifty-five peer-reviewed studies which are based on empirical evidence and which focus on entertainment videogames (rather than learning or serious ones). Through their review they cite the following psychological theories as the most influential for videogame engagement research: (1) Csíkszentmihályi's (1990) Flow Theory (originally developed for explaining optimal engagement experiences with life tasks of work or leisure), (2) Deci and Ryan's (1985; Deci 1980) Self-Determination Theory (SDT, originally discussed in education, psychotherapy, work, and sports applications), (3) Uses and Gratification Theory (Schramm et al. 1961) (U&G, originally developed to explain engagement with TV and music), (4) Davis' (1989) Technology Acceptance Model (TAM, outlines the motivations for technology acceptance), and (5) the Big Five Personality Traits (John and Srivastava 1999).

The Five Most Mobilized Framework

Below are the brief descriptions and discussions of the five most mobilized psychological theories for videogame engagement research.

Flow Theory

Flow is defined as "activities in which there is a match between high challenge and high skills." (Gregory 2013, p. 177) Csíkszentmihályi (1990) describes the conditions of flow state activities that will create an engagement with everyday life as to result in happiness. Various previous research applied the flow state conditions to

media enjoyment (Sherry 2004) and gameplay experience (Sweetser and Wyeth 2005; Chen 2007; Cowley et al. 2008). These conditions can be summarized as:

- *Clear goals:* The players can easily comprehend what their goals are and what they must do to achieve them. In a videogame, there can be a certain anxiety period before the players learn what to do and how to do it. Easing this period with tutorials and/or clear user-interface designs may result in a faster transition into the flow state.
- *Immediate feedback:* The players can instantly see and understand the results of their actions. They can also track if they are doing well or not.
- *Challenges matching skills*: The players need to ascend in a learning curve that keeps challenging them as the videogame progresses. Challenges that are too high or too low compared to the skill level of the players will both frustrate them equally.
- *Deep concentration*: The tasks that are given to the players encourage attention and concentration.
- *A feeling of control*: The players need to feel in control throughout the entire gaming experience. Unjustifiably hard-to-learn or hard-to-execute controls may disrupt the experience of flow.
- *The sense of time is altered*: The players lose track of time or the time seems to pass with more rapidity.
- *The activity is intrinsically rewarding*: The experience is worth engaging in for its own sake. The videogame awards the players for their progress.

Designing a videogame harmonious with the flow state may facilitate engagement, but there is also room for alternative approaches. Experienced players may still enjoy videogames with steep learning curves (Sánchez et al. 2009), or videogames with delayed feedback or invisible control schemes can still invoke positive gameplay experiences (Şengün, 2013).

Self-Determination Theory

Self-determination theory (SDT) suggests that intrinsic motivation is the core type of motivation for sports and play (Frederick and Ryan 1995). There are three factors that support or diminish intrinsic motivation: autonomy, competence, and relatedness. These factors have been widely adapted to gameplay and gaming experiences (Ryan et al. 2006; Przybylski et al. 2010; Deterding et al. 2011).

The feeling of autonomy for playing videogames may be accepted as inherently established since the action of play seems to be always voluntary. However, in some cases, that may not be the case (Deterding 2011). Inside the gameplay experience, the sense of autonomy deepens when the players have the perception that they are free to choose what they want to do and the in-game instructions are accordingly flexible. A sense of autonomy may be established when the videogame is not overly retributive over players' actions. This enables the players to be free to go back to the parts they have failed (or even succeeded and passed) and replay these parts to get better results or to experiment on the different outcomes, rather than being forced into singular trajectories. For narrative videogames, the intrinsic motivation is expected to increase when the players can choose different paths within the storytelling and can see that their choices affect the advancement of the narrative.

A feeling of competence is created when the players are challenged optimally and receive positive feedback (Gee 2003). The concept of competence is similar to Csíkszentmihályi's flow conditions, specifically to establishing challenges that match skills. In terms of game design, planning an optimally increasing challenge arc enhances the experience of competence. Additionally, being able to acquire new skills and access new content over time may also create instant positive feedback for the player, enhancing competence and, in turn, increasing intrinsic motivation.

Relatedness is the experience individuals have when they feel connected with others (Ryan and Deci 2001). Initially, this might only be assumed as the videogame having online multiplayer aspects, yet there are other ways to create relatedness. If a videogame is not suitable for cooperative or competitive online play, it may instead offer online scoreboards where players can compare

and compete their performance. To an extent, a sense of relatedness may also be created with online message boards or other online social interaction platforms where the players of the videogame can discuss the different aspects of their experiences. As a result, even if the gameplay itself cannot offer relatedness through multiplay, the social aura created around the videogame might.

Uses and Gratification Theory

Uses and Gratification Theory (U&T) asserts that individuals seek media and media content for a variety of gratification purposes and that their choices are "purposive, goal-directed, and motivated to satisfy their social and psychological needs or desires." (Weiyan 2015, p. 77) Contemporary research constructed several adaptations of the theory to explain videogame use (Selnow 1984; Phillips et al. 1995). Most notably, Sherry and Lucas developed a U&T measurement scale for videogame use (presented in 2003 at ICA; published in 2006) and mobilized this scale to explain the effect of gender differences in videogame genre preference, usage, and play time (Lucas and Sherry 2004).

Technology Acceptance Model

Technology Acceptance Model (TAM) and the Extended Technology Acceptance Model (referred to as TAM2) (Venkatesh and Davis 2000) focus on measuring the perceived usefulness and the usage intentions of new technology by individuals. TAM2 extends the model through the constructs of social influence (the effects of social interactions on adopting or rejecting technologies) and cognitive instrumental processes (specifically job relevance, output quality, result demonstrability, and perceived ease of use).

In its adaptation to videogame engagement, several factors of TAM are offered to have precedence: ease of use and learning opportunities instead of job relevance (Bourgonjon et al. 2010), perceived mobility and perceived skills (Park et al. 2014), and social experiences (Hsu and Lu 2004). Wang and Goh (2017) provide a meta-analysis of 50 articles that mobilize TAM2 to explain videogame acceptance, and they find that "perceived ease of use (PEOU), perceived usefulness (PU), and perceived enjoyment (PE) significantly associate with attitude and behavioral intention" (p. 662).

The Big Five Personality Traits

The Big Five Personality Traits framework is one of the most mobilized psychology scales to define personality (John and Srivastava 1999). The Big Five was adapted across a wide range of disciplines from business to learning, from personal relationships to national values, and from addiction studies to videogame use. At its core, the scale defines five dimensions to quantitatively base personality on: (1) extroversion versus introversion; (2) agreeableness versus antagonism; (3) conscientiousness versus lack of direction; (4) neuroticism versus emotional stability; and (5) openness versus closedness to experience (Costa and McCrae 1992).

Various research uncovered empiric relationships between videogame use, gameplay behaviors, and the Big Five Personality Traits. For example, Witt et al. (2011) assert that extraverted and open-to-experience youth report higher levels of videogame use. In another study, being extrovert and open-to-experience were suggested as predictors of the immersive tendency in virtual environments (Weibel et al. 2010).

Latest Additions

To complement the review of Boyle et al. (2012), a purposefully limited systematic review of research on videogame engagement published between the years of 2012 and 2017 was performed for this article. Only the top 5% relevant results of the review search were used to validate that the abovementioned theories were still in use and to discover if any new frameworks gained attention in the field. The limited review results underscored the ongoing interest in adapting the five psychological frameworks to game studies; however, novel efforts to adopt additional frameworks were also uncovered.

Data Collection and Selection Criteria

The additional review was limited to research that mobilized empirical data, focused on

entertainment videogames, mobilized an existing psychological framework, and published between the years of 2012 and 2017. The search used MIT Library's BartonPlus which includes more than seventy-five academic databases (e.g., SCI, SSCI, PsycArticles, PubMed, JSTOR, EBSCOhost, arXiv, etc., among many others). The search method used is given below. This search resulted in around 12,000 results, and only the top 5% relevant results were manually scanned.

> ("computer games" OR "digital games" OR "videogames" OR "video games") AND ("motivation" OR "engagement" OR "enjoyment" OR "immersion" OR "absorption" OR "gratification") NOT ("learning" OR "education" OR "gamification")

Results

The manual analysis resulted in 31 studies using the following frameworks: SDT (27%), Flow Theory (19%), Internet Gaming Disorder Scale (13%), Social Identity Theory and Social Capital (13%), U&G (10%), Regulatory Focus Theory (6%), Social Cognitive Theory (6%), TAM (3%), and The Big Five Personality Traits (3%).

The results showed that SDT and Flow Theory were still the most mobilized psychological theory adaptations in explaining videogame engagement. Theories of Social Identity, Social Capital, and Social Cognition had diverse levels of adaptations in building and verifying scales. Two newcomer frameworks – Internet Gaming Disorder (IGD) Scale and Regulatory Focus Theory – were noteworthy additions and they are discussed below.

Internet Gaming Disorder (IGD) Scale

American Psychiatric Association's 5th edition of Diagnostic and Statistical Manual of Mental Disorders (DSM-5) introduced the Internet Gaming Disorder (IGD) Scale in 2013. IGD mobilizes the learnings from previous addiction scales and adapts them to measuring disorderly online gaming practices.

While IGD is already put to use by various studies (e.g., measuring internet gaming disorder in Taiwan by Ko et al. 2014 or in Germany by Rehbein et al. 2015), there are also critics of the scale (Király et al. 2017) especially on the vagueness of "diagnostic criteria and appropriate symptoms." (Bean et al. 2017, p. 378) In any case, the scale is likely to have more exposure and validation in the upcoming years.

Regulatory Focus Theory (Regulatory Focus and Regulatory Fit)

Regulatory Focus Theory (Higgins 1997) asserts that individual behavioral patterns and decisions are directed by personal assessment of loss and gain. According to their assessments of loss and gain, individuals develop and act on two self-regulatory orientation foci: promotion or prevention (Crowe and Higgins 1997; Higgins 2002). Individuals with promotion focus act on participation, advancement, achievement, and growth, while, individuals with prevention focus act on security, safety, and responsibility (Ozturkcan and Sengun 2016). Moreover, individuals might experience negative or positive fit with the task at hand and their self-regulatory orientation. The positive regulatory fit will increase the engagement of the individuals with the task at hand, while the negative regulatory fit will distance them (Higgins 2000, 2005; Higgins et al. 2001).

Ozturkcan and Sengun (2016) adapt regulatory fit in explaining abnormal gaming behavior in massively multiplayer online (MMO) videogames. In this example, players with promotion focus experience a regulatory fit in the beginning of the MMO gaming experience, gaining levels, skills, items, etc. in an easy and fast fashion while discovering new virtual places and adventures. However, as the videogame progresses toward the maximum level, goals become harder to achieve, requiring long hours and cooperation with a larger number of players. Discoveries also become scarce and hard to make. At this stage, promotion focus players start to experience a negative fit and find it easier to quit the videogame to move on to other experiences. For prevention focus players, the situation is opposite. At the beginning of the MMO gaming experience, prevention focus players may proceed slower since they do more research on decisions that might affect their endgame (e.g., selecting the best race or class to play; the most advantageous

adventures, skills, or items to focus on; etc.). In the endgame, they may experience a very strong positive fit, since they have accumulated virtual gains (e.g., strong characters, hard-to-find items, social capital among other players, in-game achievements, etc.) and find it harder to quit the videogame. In fact, various research underscores that addictive or compulsive gaming behavior is frequently the result of players trying to protect their in-game investments (Wan and Chiou 2006; Lu and Wang 2008; Peters and Malesky 2008).

Conclusion and Discussion

This article provides a snapshot of the efforts of adapting previous psychological theories and frameworks regarding engagement and motivation to the field of videogame studies. Flow Theory, Self-Determination Theory, Uses and Gratification Theory, Technology Acceptance Model, the Big Five Personality Traits, and Regulatory Focus Theory are identified as the psychological frameworks that were most mobilized for explaining videogame engagement. Internet Gaming Disorder (IGD) scale is an outcome of this adaptation efforts and was published as a part of DSM-5.

The main advantage of mobilizing previous psychological theories to the field is the ability to access a large body of empirical data and methodologies associated with them. However, it should also be acknowledged that adaptation into the field requires meticulous customization, validation, and novel assessments of the subject matter. Videogame designers, developers, and researcher would benefit from referring to psychological methodologies and knowledge in explaining player behavior and designing player experiences.

Cross-References

- ▶ Cognitive Psychology Applied to User Experience in Video Games
- ▶ Game-Based Interventions in Public Health: Exploiting the Engaging Factor of Gameplay

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Virtual Acoustics

▶ Sound Spatialization

Virtual Body-Ownership

▶ Perceptual Illusions and Distortions in Virtual Reality

Virtual Camera

▶ 3D-Rendered Images and Their Application in the Interior Design

Virtual Environments

▶ 3D Puzzle Games in Extended Reality Environments
▶ Crowd Evacuation Using Simulation Techniques
▶ Mixed Reality
▶ Planetary Generation in Games
▶ Virtual Reality and Robotics
▶ Virtual Reality Systems, Tools, and Frameworks

Virtual Gashapons

▶ Loot Boxes: Gambling-Like Mechanics in Video Games

Virtual Hand Metaphor in Virtual Reality

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Synonyms

3D interaction; 6 DoF interaction

Definitions

Virtual Hand Metaphor is a set of interaction techniques for selection and interaction with objects that are within reach of a user's arm. Virtual Hand Metaphor closely resembles real-life interaction with objects; the user manipulates the object directly using a virtual representation of their hand or hands. A more general term (3D interaction) includes Virtual Hand Metaphor as one of the common approaches to interaction with virtual objects in an immersive environment.

Introduction

Object selection and manipulation are basic tasks in 3D user interfaces. One way the task can be realized is through Virtual Hand Metaphor. In the spirit of natural-user interfaces (Buxton 2007), the Virtual Hand Metaphor borrows from the way users interact with real objects using their hands and adapts it for manipulation of objects presented in an immersive environment.

Types of Virtual Hand Techniques

In the Virtual Hands Metaphor, objects are acquired and manipulated in a way that closely resembles real-world touching and gasping; that is, users control a virtual hand in order to acquire,

reposition, rotate, scale, distort, or otherwise modify objects in the 3D world. Due to current technological implementations, virtual hands are usually less precise and result in slower completion of a task than alternative techniques such as Virtual Pointing. However, virtual hands provide better immersion and increase a perception of virtual body ownership. Virtual hands are usually implemented as one-to-one mapping of the user motor space (the volume of space reachable by a user's motor system, e.g., user's arm) and the control space (the volume of space reachable by a virtual hand in the immersive system).

Because of the similarity to real-life interaction, techniques based on Virtual Hand Metaphor are prone to many of the same disadvantages the interactions in the real world are; in particular, limited reach and the potential for fatigue (Bowman et al. 1999). In consequence of the focus of the HCI community on increasing performance and decreasing fatigue, only a small number of techniques based on Virtual Hand Metaphor were developed and published, as compared to the large number of techniques based on virtual pointing metaphor (Argelaguet and Andujar 2013).

Some variants of Virtual Hand Metaphor, such as Go-Go technique (Poupyrev et al. 1996), address limitations on reach. In Go-go technique, the user's motor space is not mapped one-to-one to the control space. Instead, a custom Control-Display gain function is used. This increases the reach of the virtual hand beyond the limits of user's arm length.

The problem of fatigue in using virtual hand technique for prolonged time remains unsolved. Previous studies quantify the amount of fatigue, or so called "gorilla-arm effect" (Hincapie´-Ramos et al. 2014). Keeping an arm raised for a prolonged time renders the virtual hand impractical for long-term use. Despite these results, many applications developed for consumer-grade virtual reality systems, such as Oculus Rift CV1 with Oculus Touch, utilize virtual hand metaphor as the primary mode of interaction.

Input Devices

Virtual hand requires an input device providing at least six degrees of freedom (DoFs) to correlate rotation and translation of the real and virtual hand along all three axes. Some input devices provide more degrees of freedom to simulate virtual finger movements. High-precision hand-held input devices used to implement virtual hands include magneto-optical trackers, such as Oculus Touch, HTC Vive Controller, and PlayStation Move controller. Virtual hands can also be realized as a free-hand interaction using optical hand tracking from markers-based high-precision motion capture systems, such as VICON or PhaseSpace, to low-cost markerless systems, such as Leap Motion, and

Virtual Hand Metaphor in Virtual Reality, Fig. 1 Virtual Hand Metaphor implemented for Oculus Touch, 6DoFs magneto-optical motion tracking device

Microsoft Kinect. Alternatively to optical tracking, wearable input devices may be used, including motion capture suits (e.g., Perception Neuron suit), off-the-shelf smartwatches (Pietroszek et al. 2017; Kharlamov et al. 2016), electromyographic sensor (Thalmic Myo armband), or digital gloves (Senso glove) (Fig. 1).

Conclusion

Virtual Hand Metaphor is a standard metaphor for interaction with objects in immersive systems. It allows for interaction with objects that are within the reach of user's arm length. For many interaction tasks, Virtual Hand Metaphor is slower and causes more fatigue than alternative solutions, such as Virtual Pointing Metaphor. Nevertheless, it is popular in consumer-grade virtual reality systems because it is a natural translation of a user's interaction with real-life objects, thus increasing immersion and perception of virtual body ownership.

Cross-References

► Virtual Hand Metaphor in Virtual Reality

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Virtual Human Character

► Virtual Human for Assisted Healthcare: Application and Technology

Virtual Human for Assisted Healthcare: Application and Technology

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Synonyms

Assisted healthcare; Realism; Virtual human character

Definition

Modern healthcare is constantly discovering and exploring the contributions that virtual reality can make to healthcare. The adoption of virtual human characters has had a success growth, in the past decades, in education, movies, games, and embodied conversational agents (ECAs). However, the growing interest of virtual reality in healthcare might stimulate a renewed interest in virtual human character. Therefore, this paper introduces the potential application areas of virtual human character (VHC) in healthcare from the point of view of realism and draws attention to the technology behind VHC as it pertains to realism.

Introduction

Modern healthcare is constantly discovering and exploring the contributions that virtual reality can make to healthcare. The usefulness of virtual reality in healthcare was discovered as far back as the 1990s during a surgery planning when a team of medical practitioners needed to visualize some complex data for a surgery (Chinnock 1994). Whenever the term "virtual reality" is used, attention is usually directed toward a three-dimensional (3D) imaginary world that allows for integration of human senses and interaction within a computer-generated environment using devices, such as head-mounted display, DataGloveTM, or a joystick (Satava 1995). However, there is the other aspect of virtual reality that is minimally discussed in literature, the virtual human character. Virtual human character (VHC) is a computer-generated human look-alike that could act as replacements for human in virtual environments. The VHC, this paper is particularly concerned with, is the one to do with the human face. The adoption of virtual human characters has had a success growth in other aspects of life, such as education, movies, games, and embodied conversational agents (ECAs).

Virtual human character as human look-alike should be able to express facial expression, facial emotions, and exhibit interaction characteristics, and these are fundamental components in achieving realism. Currently, there is a growing interest of virtual human in healthcare. Though the "uncanny valley" has in some ways slowed the focus on VHC in other application areas (Kokkinara and McDonnell 2015), in healthcare, it should never be an object of concern. The reason is this: imagine being a medical student and the virtual agent instructor lack human characteristics, will you have a committed interest and engagement during the training? Realism for virtual humans is key for such a scenario. Therefore, VHC should be developed in such a way that the "uncanny valley" effect is minimized/negligible as much as possible. Simply put, uncanny valley is human look-alike characters that lack real human emotions.

A great deal of healthcare systems requiring virtual humans needs realism to sustain the goals of virtual human adoption. A study in Seyema and Nagayama (2007) show that higher levels of animation of virtual faces are better perceived as being appealing. The question is: does this apply to all applications? This paper serves to assemble at one point the application areas of virtual humans in healthcare with emphasis on the dependency of the VHC on realism based on the application areas. Also, highlight will be thrown on current state of VHC research and technology relevant to virtual human assisted healthcare.

The rest of the paper is organized as follows. In section of "Virtual Human Application in Healthcare", the application areas in healthcare where virtual human requires realism is presented. The technology, through literatures, behind virtual human as it pertains realism are discussed in section of "Virtual Human Character Technology". In section of "Virtual Human Character Challenges" is a highlight on observable challenges of the virtual characters in realism. The conclusion is presented in the last section.

Virtual Human Application in Healthcare

Virtual human in healthcare has several applications, some of which are identified and discussed independently as listed in Magnenat-Thalmann and Thalmann (2004).

- Virtual patients for surgery and plastic surgery
- Virtual humans for treatment of social phobia and virtual psychotherapies
- Virtual teachers for distance learning, interactive assistance, and personalized instructions
- Virtual human for simulation-based learning and training

Virtual Patients for Surgery and Plastic Surgery

During surgery planning, surgeons usually simulate how a procedure will play out on a given patients face by using a simulated image of a patient. The simulation offers an avenue for the patient to build confidence in the doctor and can also help doctors understand and practice the procedure that best fits a given patient. Virtual humans are used in surgery to practice aesthetics and conduct maxillofacial surgery, oral surgeries, etc. Since the interest is more on the face of virtual humans' character, the discussions here are limited to literatures with emphasis on the face of the virtual character. The research work by Patel et al. show that high face fidelity of virtual humans helps surgery patients interact easily with VHC (Patel et al. 2013). The use of virtual humans in patient surgery is one of the oldest areas of virtual human application in healthcare (Raibert et al. 1998; Altobelli et al. 1993; Rosen et al. 1996). The study in Karaliotas (2011) used virtual patients to provide normal and pathological conditions in the simulation of human anatomy and with emphasis on realism. In Smith et al. (2005) a virtual reality model is created for simulating aesthetic surgery procedures. The adoption of virtual humans in surgery help patients know and experience what can be expected from a surgery (Khor et al. 2016). Thus, the patient and doctor can have a good understanding of successes and implications of certain procedures.

Virtual Humans for Treatment of Social Phobia and Virtual Psychotherapies

In Sjolie (2014) virtual characters are proposed as a tool for helping dementia patients and persons who are experiencing cognitive decline. However, the extent to which realism is to be attained for this use case is not yet clear. What is clear is to be able to help fight phobia among social phobic individuals requires the scene of commonly experienced social woes to be constructed to mimic real-world scenario (Didehbani et al. 2016). The scene alone is not enough; rather the manipulation of the virtual human verbal and behavioral responses is an avenue to assert control of the level of therapy measures invoked with the use of VHCs (Brinkman et al. 2008).

Anxiety is one of the medical disorders that can be medically treated through psychotherapy. The treatment process involves psychological counseling which comprises of cognitive-behavioral therapy (CBT), psychotherapy, or a combination of therapies. Pan et al. (2012) through their study showed that presenting socially anxious participants to a VHC help in dealing with situations that might trigger anxiety. The VHC does not necessarily have to be human look-alike nevertheless should be able to exhibit human facial gestures and expressions, give and maintain eye contact, and talk and interact with the human participant (Pan et al. 2012; Grillon et al. 2006).

Virtual Teachers for Distance Learning, Interactive Assistance, and Personalized Instructions

The teacher's role in a learning environment is void of learning without interaction, eye contact, exhibiting emotions, and expressing such emotions. A virtual agent should easily assume these behaviors and characteristics within a learning environment to be able to meet the expectations and acceptance of its human users.

Healthcare, particularly medical and nursing education and training, often involves the acquisition of knowledge through use of voluminous study materials which are constantly being updated, thus presenting a challenge to learning. Virtual reality has stimulated the increasing excitement on the integration of virtual humans in medical training process. According to a study on support for technology in healthcare education in 2010 Kron et al. (2010), 98% of over 200 medical students supported the inclusion of virtual teachers in healthcare training. Another study in Gromala et al. (2015) suggest that training of mindfulness meditation, a healthcare intervention program which has been used over decades to

Virtual Human for Assisted Healthcare: Application and Technology,
Fig. 1 Medical simulation-based training. (Source wiki)

reduce addictive behaviors, is more effective with the use of virtual humans than with humans themselves.

Virtual Human for Simulation-Based Learning and Training

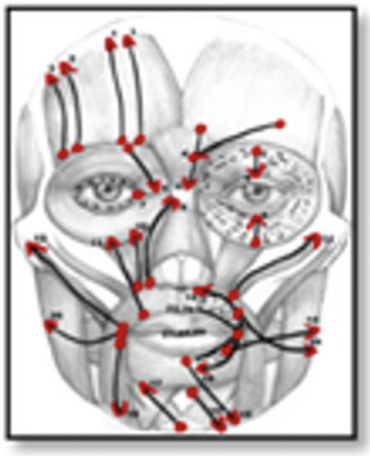
Realism has been our focus so far, but it is more heightened here because simulation-based learning and training for medical practitioners require high level of realism. Why is this the case? The simulation should mimic the real thing. For instance, imagine that virtual human suffering from internal pains (depicting a real patient; see Fig. 1) is presented as practical bed for junior doctors, the virtual human should be able to express pains when touched at various locations of the body pain is experienced. A VHC that lacks the ability to show emotions and express feelings will send across a different skill set and knowledge other than the required to the team of the junior doctors being trained. Therefore, VHC in simulation-based learning for healthcare practitioners should be able to simulate the real thing. The application of VHC for simulation-based learning and training in healthcare are endless. The study (Bertrand et al. 2010) used virtual humans to simulate hand hygiene practices for the full medical hygiene cycle: doctor, nurse, and patient. According to Zielke et al. (2010), a huge advantage of virtual humans in simulation of reality for medical education is that the learning environment and scenario of design can be adapted to simulate various levels of medical conditions; high-risk and low-incidence cases. The trainees can as well be able to learn the various factors such as patient regional, social, economic, behavioral, and cultural factors that can influence diagnosis and treatment sessions with a patient.

Virtual Human Character Technology

In the preceding session, various literatures point to the significance of realism of VHC as it pertains to healthcare. In this section, we seek the technology as identified in literatures for achieving realism for virtual humans. Therefore, the reviews of literature are based on the underlying methodologies that are currently used for VHC realism and are discussed under key topics in the succeeding subsections.

Facial Action Coding and Expression

The facial action coding system (FACS) is adversely applied for understanding virtual character model (Kopp et al. 2006). In Shapiro (2011) FACS was used to achieve virtual character simulation, control, and realism. (Čereković and Pandži 2011) employed neural networks together with a manual synthesis of face expressions, speech, and gestures with facial animation model. This work was improved by Wang et al. (2010). Their work made use of the action units (AUs) which defines 46 points on the face. These units are assumed to house the regions of the face facial muscles or group of muscles contract and reveal the face emotions. The Fig. 2 shows the



Virtual Human for Assisted Healthcare: Application and Technology, Fig. 2 Action units and main codes on the face (Morten Havmøller Laursen 2012)

simpler AUs for a typical human face. The arrows show the directions of movement of the AU, while the endpoint red arrows are the center of mass for emotion. To achieve facial expressions alongside continued human dialogue emotions, latent semantic analysis concept is adopted for embedded conversation for virtual characters (Zhang et al. 2013).

Character Deformation and the Physics Model

Facial deformation can be achieved through manipulating on element-wise basis, mesh units by some deformation functions. Multi-facial expressions can be created by combining muscles, though not the structure, and representing spline surfaces as hierarchical B-splines (Thiebaux et al. 2008). A muscle model was created by Platt and Badler in 1981 using the human facial structure and to generate multi-facial expressions; they applied the muscle arcs to flexible meshes. This approach was also adopted in (Ali et al. 2018), and the efficiency of synchronizing speech with the virtual character was evaluated using a context-dependent viseme. The observed that the number and distribution of fiduciary points effect on the quality of viseme presentation. The study in Leigh and Zee (2006) on physics muscle resulted in Greta: a virtual agent developed by Pasquariello and Pelachaud (2002) to synchronize gestures with speech to coordinate.

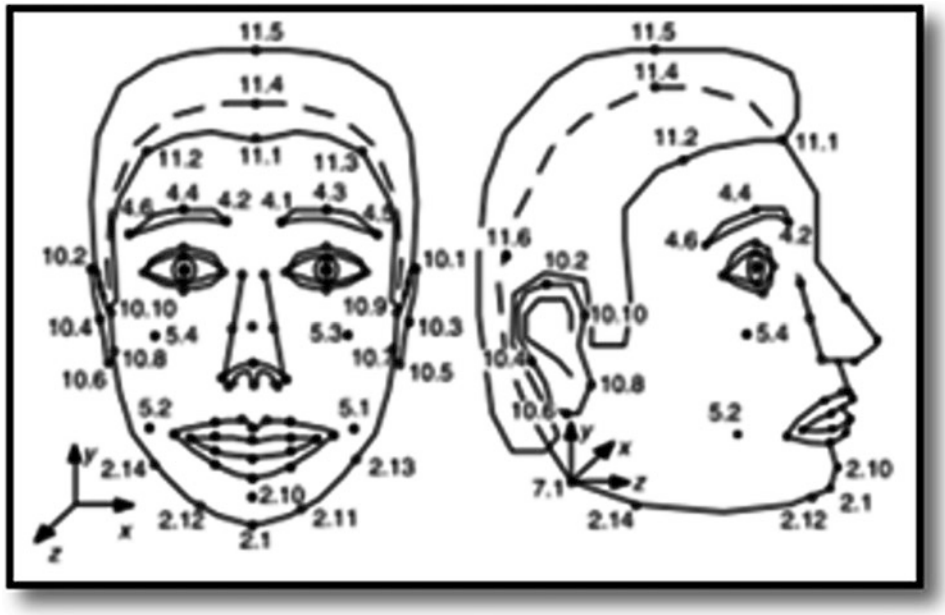
Performance-Driven Virtual Character

The performance-driven VHC is useful in circumstances where difficulties in controlling facial animation result from inaccuracies of movement tracking. This is a significant issue in real-time healthcare scenarios, especially for simulation-based training. In simulation-based training, interactivity of characters must be ensured to naturally combine motion and expressions. Deng and Neumann (2008) proposed to synthesize an expressive speech animation system through control at the phoneme level. In Hofer et al. (2008) an automatic lip-motion trajectory synthesis of the ECAs was presented. The work was extended by Zoric et al. (2011). They used animation trajectories achieving desired lip-speech synchronization with the ECA.

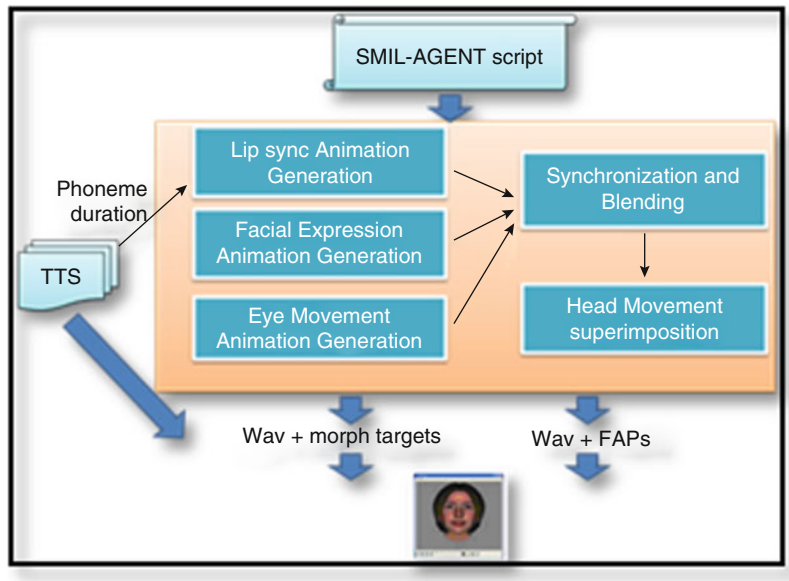
MPEG-4

Several literatures adopt the MPEG-4 technique in facial animation (Parke and Waters 2008). The MPEG-4 is used for generating animation based on three face data; face definition parameters (FDP), the face animation parameters (FAP), and the FAP Interpolation Table (FIT), which define the FAP interpolation rules. The FDP is used create 3D face geometry. The FAPs is designed to encrypt animation facial emotions, expressions, and speech pronunciation. After identifying 68 face parameters (see Fig. 3), they are animated through the face animation parameter units (FAPU). To achieve neutral facial emotion, the FAPUs are used to calculate distance between face units. Balci et al. (2007) created the Xface tool which is for the ECA using the MPEG-4 and achieved key-frame driving using the SMIL-agent scripting language. This method is visually depicted in Fig. 4. The purpose of their method is to be able to mimic human expression and emotion in the absence of gesture.

Queiroz et al. (2009) used the MPEG-4 attain parameterization of face with a high-level facial actions and behaviors of virtual characters that can interaction human user. In Zoric et al. (2011) synchronized facial gestures



Virtual Human for Assisted Healthcare: Application and Technology, Fig. 3 Some facial features points for the face as the MPEG-4 standard (Ali et al. 2018)



Virtual Human for Assisted Healthcare: Application and Technology, Fig. 4 The SMIL-Agent script processing (Balcı et al. 2007)

and speech to virtual character using MPEG-4, it lacked emotions. Their work was improved in Kessous et al. (2010). In Kessous et al. (2010) a Bayesian classifier was used to identify the different types of emotions for different gestures, which they adopted to achieve human-like character but lacked face movements. Arsov et al. (2010) developed an approach

that makes virtual character achieve interaction and learn cued speech.

Visual Speech Virtual Character

Facial expression alongside recorded speech is difficult to model. The reason is this: The human language comprises of vocabulary, phonemes, and speech coarticulation, which need to be integrated to achieve realism (Arsov et al. 2010). In Skantze and Al Moubayed (2012) the IrisTK, a toolkit designed for multiparty face-to-face interaction, while the Situation, Agent, Intention, Behavior, and Animation (SAIBA) is developed to compute ECA communication and human behavior realization (Bevacqua 2011), Berger et al. (2011) incorporated hissing and buzzing to speech synchronization with virtual character.

Virtual Human Character Challenges

The exhibition of facial expression, emotions, and interaction for VHC are not yet as good as that of a real human. However, just to avoid "uncanny valley," it is widely acceptable if the VHC can communicate all the important expressions of emotions of the human, make eye contact, and engage in interactive activities.

To simulate the emotional state of the virtual character, it is important to determine facial expressions and behavioral characteristic that the model is to mimic prior to modeling, for example, lip-syncing synthesis animation. Lip-synching has existed for decades, but the real challenge originates in blending emotions with lip-synching to produce fuller and richer character animation. For model-based talking head systems, it is more elegant to work on the facial animation parameters to bring about coarticulation effects. Giving information to a user in the form of a talking head increases acceptance level of the VHC by the humans. Therefore, the integration of speech to an animated character may also make the use experience acceptable to users, especially for social phobic patients.

During synchronization of the VHC with human emotions identified during FAP, conversation should be simulated to obtain the varying emotional states of the human model, and care should be taken to ensure that the lexicon obtained contains enough emotions variables before encoding. This is to guarantee that different personalities and dissimilar emotions required in a dialogue are captured. More also, eye movements are very important factor for achieving realism for VHC. The believability of the virtual human is not necessarily of being human look-alike but in its ability to maintain facial behaviors that mimics human behavior, such as eye contact, blinking, and squinting.

Conclusion

The future holds a great potential for VHC in healthcare. The benefits of VHC in healthcare are endless and will serve to enhance the medical practices, therapies, and education. The successes of VHC in other fields of application, such as military, games, movies, and sports gave us a glimpse of its possibilities which will continue to drive the interest of VHC developers, researchers, and the medical practitioners, who are the healthcare end users. Therefore, there lies the challenge of achieving valuable experiences, limiting "uncanny valley" effect while attaining realism, between the virtual human and various application usage scenarios in healthcare. Finally, the design features that enables the VHC to assume human behavior and character which would make virtual human in healthcare enjoyable and readily adopted is still lacking. Though, the sole purpose should not only focus on human behavior but richly capture material content as well, especially for simulating an educational instructor or surgery.

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Virtual Locomotion

► Natural Walking in Virtual Reality

Virtual Point Light

► High-Performance Many-Light Rendering

Virtual Pointing Metaphor

► Raycasting in Virtual Reality

Virtual Pointing Metaphor in Virtual Reality

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Synonyms

3D pointing; Distal pointing

Definition

Virtual Pointing Metaphor is a set of interaction techniques for selection of objects that may be outside of reach of user's arm. Virtual Pointing Metaphor closely resembles real-life pointing with a finger: the user points at the object and confirms its selection with a mid-air gesture, a voice command, or a button click. Once selected, the object can be translated, scaled, rotated, distorted, or otherwise manipulated. In the context of large screen interaction, virtual pointing is often referred to as "distal pointing." A more general term, 3D pointing, includes virtual pointing metaphor as one of the common approaches to selection of objects in immersive environments.

Introduction

Object selection is a fundamental task in 3D user interfaces (Bowman et al. 2004). Most interaction tasks in immersive systems start with a selection of an object of interest. A selection technique must facilitate the indication of an object, confirmation of its selection, and should provide visual, haptic, or audio feedback during the selection task. One way a selection task can be realized is through virtual pointing metaphor. In the spirit of natural-user interfaces (Buxton 2007), the Virtual Pointing Metaphor borrows the familiar pointing

gesture from user interactions with real objects and adapts it for selection of objects presented on a large screen or in an immersive environment.

Virtual Pointing was initially developed for interaction with 2D objects presented on large displays, before it was adapted for interaction with immersive systems. One of the earliest examples of Virtual Pointing Metaphor is the demonstration entitled Put-that-there (Bolt 1980). This interaction technique combines voice input with mid-air gestures, allowing objects to be moved on a large display in front of the user. By using a combination of voice and mid-air hand gesture, the technique demonstrates how multimodal input can enhance pointing. However, "Put-that-there" technique enabled selection of 2D objects only. Selection of objects presented in virtual reality requires another degree of freedom – the depth – to reach the objects positioned at a various virtual distances from the user.

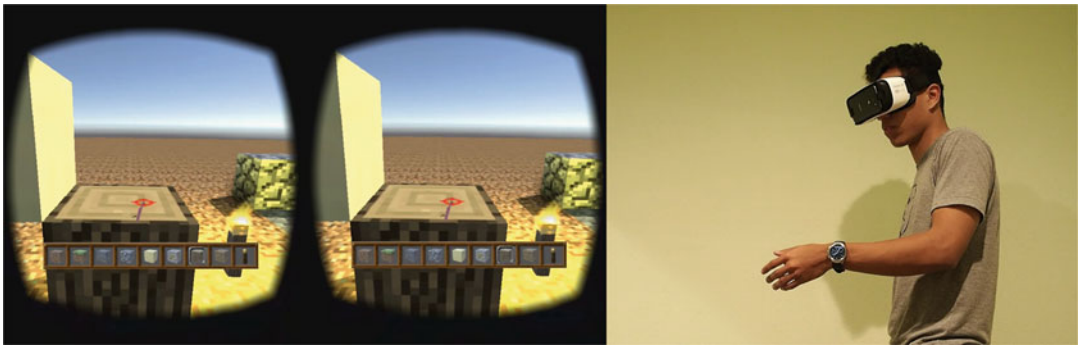
Types of Virtual Pointing Techniques

The first type of virtual pointing technique is the point cursor. The point cursor enables users to freely move a 3D point cursor (Argelaguet and Andujar 2008) within the 3D environment. The technique resembles a mouse cursor, but requires manipulation of the cursor position along the z-axis. The 3D point cursor is usually represented as a sphere or a cross-hair, rather than an arrow. The input devices position in user's motor space (the volume of space reachable by user's motor system, e.g., user's arm) is directly translated into the cursor's position in the control space (the volume of space reachable by point cursor in the virtual system). To reach the target object, the user moves the input device. The function describing how the input devices movement and rotation in the motor space translates into the selection tool movement in the control space is called Control-Display ratio (C/D ratio). C/D ratio is application specific and can be determined by the user or the system designer.

The family of Raycasting interaction techniques is another category interaction techniques that belong to virtual pointing metaphor. In Raycasting, the direction of user pointing is presented as a ray originating at the user's input device. Raycasting techniques exists in many variations (Argelaguet and Andujar 2013), developed to address various challenges in 3D interaction, such as accuracy and speed trade-off, and occlusion. The first Raycasting technique called "laser gun" was introduced by Liang and Green (1994). Common modifications of the technique include adjusting the shape of the selection cursor, or the ray. In Aperture Selection technique (Forsberg et al. 1996), user can manually adjust the selectable areas apex angle. Some techniques combine a ray with a 3D point cursor that is contained along the ray. For example, in Depth Ray and Lock Ray (Grossman and Balakrishnan 2006) from all objects intersected by the ray, the one that is closest to the 3D cursor that can move along the ray is the one that is selected. In 3D BubbleCursor (Vanacken et al. 2007), the size of the spherical cursor at the ray's end expands or shrinks automatically to reach the object closest to its center.

Input Devices

Virtual pointing requires an input device providing six degrees of freedom (DoFs) – rotation and translation along all thee axis – in order to provide user with full control over the position and rotation of the selection tool (a point cursor or a ray). High-precision hand-held input devices used to implement virtual pointing include air mouse, magnetic tracker, Oculus Touch tracker, HTC Vive Controller, and PlayStation Move controller. For casual 3D interaction, techniques utilizing a smartphone or a Wiimote were developed (Pietroszek et al. 2014, 2015). Virtual pointing can also be realized as a free-hand interaction using optical hand tracking, ranging from high-precision motion capture systems, such as VICON or PhaseSpace, to low cost systems such as Leap Motion, and Microsoft Kinect. Alternatively to optical tracking, wearable input devices may be used, including motion capture suits (e.g., Perception Neuron suit), off-the-shelf smartwatch



Virtual Pointing Metaphor in Virtual Reality, Fig. 1 TickTockRay (Kharlamov et al. 2016): An example 3D pointing technique for virtual reality using Virtual Pointing Metaphor and off-the-shelf smartwatch as an input device

(Pietroszek et al. 2017; Kharlamov et al. 2016), electromyographic sensor (Thalmic Myo), or digital gloves (Senso glove). When the input device does not provide 6 DoFs, fixed-origin virtual pointing techniques can be used as an alternative (Jota et al. 2010) (Fig. 1).

Conclusion

Virtual pointing is a standard metaphor for selection of objects in virtual reality systems. For non-occluded interactions, where target objects are not hidden behind other objects, or when the target objects are outside of reach of the user's arm, virtual pointing is also the most efficient and ergonomic pointing metaphor available.

Cross-References

► Virtual Hand Metaphor in Virtual Reality

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Virtual Pottery (VP)

▶ Imagineering Ceramic Pottery Using Computer Graphics

Virtual Presence

▶ Presence and Immersion in Virtual Reality

Virtual Reality

▶ 3D Avatars in Virtual Reality Experience
▶ 3D Puzzle Games in Extended Reality Environments
▶ Accessibility of Virtual Reality for Persons with Disabilities
▶ Collaborative Engineering and Virtual Prototyping Within Virtual Reality
▶ Deep Reinforcement Learning in Virtual Environments
▶ Diversity in Gaming and the Metaverse
▶ EEG as an Input for Virtual Reality
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▶ Foundations of Interaction in the Virtual Reality Medium
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▶ Mixed Reality
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▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
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▶ Virtual Reality Applications in Education
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▶ Virtual Reality Game Engines
▶ Virtual Reality Proton Beam Therapy Unit: Case Study on the Development
▶ Virtual Reality Retailing
▶ Virtual Reality Stereo Post-Conversion After Effects Workflow

Virtual Reality and Robotics

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Synonyms

Augmented Reality; Augmented Virtuality; Cyberworld; Cyborg; Extended Reality; Four-Legged Robot; Humanoid robot; Mixed Reality; Quadruped Robot; Real Environment; Robot; Virtual environments; Virtual Reality

Definition

Mixed Reality (MR) joins both physical and digital worlds, resulting in a new reality that applies the advancements in computer vision, graphical

processing, display technologies, input systems, and Cloud computing (Microsoft 2022).

With the introduction of MR, Milgram and Kishino (1994) enriched the concept of Virtuality Continuum (VC), which describes the MR gradient, having the real environment and the virtual environment on opposite sides of the spectrum, and Augmented Reality (AR) located closer to the real environment. On the other hand, Augmented Virtuality (AV) is placed closer to the virtual environment.

AR is a reality that joins the real world and actual objects with semitransparent pictures displayed with the help of a certain device. Virtual Reality (VR) is a real 3D environment created with a computer that enables the user to interact in real time with his surroundings (Yount 2004).

A robot is defined as a machine that looks similar to a living creature with the ability to move autonomously as well as perform complex actions (Merriam-Webster 2022).

Robots can seem as MR entities as they are a combination of virtual attributes like computer states and abilities. In addition, robots have a physical manifestation with which they are able to interact with the real world (Wang 2011). Robots are found in multiple shapes with different capabilities, such as humanoid and quadruped robots.

Humanoid robots physically resemble human beings with legs and arms and mimic human behavior. They are made with complex designs to enable movement in various directions. For this reason, they tend to be more expensive and difficult to build (Ben-Ari et al. 2018).

Quadruped robots have four legs, and they are usually faster and more stable than biped robots (Atique et al. 2018).

Introduction

With the rapid development of technology, many ways to combine digital and physical reality have been designed, creating Mixed Reality (MR). This term was introduced in 1994 by Paul Milgram and Fumio Kishino in their paper "A Taxonomy of Mixed Reality Visual Displays." Since then, many applications using Virtual Reality (VR) to contribute for MR experiences have been presented, incorporating a variety of elements, like robots.

Virtual Reality (VR) and Robot Development

Most robots are used for safety and manufacturing purposes. For example, Pérez et al. (2019) mentioned that some manufacturing tasks are too complex to be automated. That is why, a relationship between humans and robots on collaborative tasks was encouraged, using VR to create a virtual environment with an interface that directly associates robots with its controller.

Being used for training, Pérez et al. (2019) developed a VR environment that offers a simulation that relies on sensory inputs from the user creating a 3D environment with the intention of being fully submerged in the simulation. This was accomplished by replicating the pragmatic behavior of items.

An accurate 3D virtual representation was achieved by doing meticulous scans of the environment, including walls, objects, tools, machines, panels, pipelines, lamps, boxes, etc., and considering textures, colors, and lighting effects. It concluded that the use of virtual interfaces and scenarios to interact with industrial robots would make the most of VR capabilities creating flexible, safe, and efficient applications to enhance training and ultimately accomplish safe real-time interaction.

In addition, the use of VR is a developing tool for the construction of quadruped robots, including simulating the walking mechanics of a quadruped robot on a slope, making use of a Virtual Modeling Language (VRML), and creating a modeling scene in MATLAB to come up with a road-mapping simulation (Wang et al. 2014).

By observing the behavior of the simulation curve, the walking stability of the robot is studied to demonstrate how a displacement of the curve impacts the gravity forces applied to the robot to

displace it smoothly. The applied simulation walking elements were the following: (1) the quadruped walking is always periodic motion; and (2) the robot body must not collide with the ground (Wang et al. 2014).

The final simulation was useful to demonstrate the effectiveness of the developed non-fragile robust controller showing a greatly anticipated control performance, which is also relevant for the robot's planning and controlling walking strategy. The test carried over the simulation confirmed the viability and stability when walking on a slope (Wang et al. 2014).

More on the matter, Livatino et al. (2021) identified that most robotic systems with a wide variety of sensors allow knowing an operating robot's current status. However, the understanding and using the high amount of data provided to the operators creates a challenge, especially in the remote teleoperation of robotic vehicles. For this reason, they developed an interface using MR and visual elements to present the information within the user interface.

MR was applied to develop a design interface with an intuitive representation of the information focusing on the required elements for proper control of the vehicle to support operators while driving and retrieving sensor data using graphic elements joining stereoscopic views with head-mounted displays to improve performance reinforcing operator's situational awareness. In addition, a 3D model of the region where the robot would be operating was developed, taking into consideration the environmental geometrics of an outdoor scenario. This is interesting as most VR models map indoor premises (Livatino et al. 2021).

The proposed design included interfaces combining the following elements: single-window representation, video-synthetic images, intuitive data viewing, and regional and directional visual aids. It was tested among 12 users to get feedback on the learning experience and acceptance. The element that had a higher level of performance was the one based on VR, showing how beneficial the uses of these resources can be when testing remote-vehicle teleoperation skills and data analysis (Livatino et al. 2021).

Virtual Reality (VR) and Quadruped Representations

Moreover, on the matter of using VR, due to the COVID-19 epidemic in 2020, many museums had to close their doors to the public, causing significant economic losses. Therefore, many museums had to develop new supporting programs to remain relevant and renew the way interaction with their audiences took place. Some of them used VR technologies to enhance engagement to create distant user experiences.

One relevant example is the Smithsonian Museum, which started 3D scanning as part of its exhibit. After improving the process, it opened an online exhibition on its website portraying the scanning of most of its productions. Then, taking it to the next level, they partnered with Instagram to use the app to display a virtual representation of their artifacts in people's personal spaces using AR (Anthes 2021).

The use of VR to get people to interact with exhibits at museums is a tool that has been developed before. For example, in 2019, the American Museum of Natural History in New York City used this element to create an exposition where visitors could piece together the skeleton of a T. rex dinosaur. At the end of the exhibition, an animation of a real-life sized T. rex was projected on a screen that interacted with the people passing by, snapping them if they stuck around long enough (Gramling 2019).

Conclusion and Discussion

The possibilities that merge with MR are endless as technological tools can be implemented in many creative ways to ensure an exciting experience for the user. On the matter of joining robots and VR, it has been seen that educational and recreational approaches have already been explored. However, a lot of research is needed to properly exploit the advantages that a virtual environment can provide, for example, using it to teach robot control or enhance educational techniques, among many other applications.

Cross-References

- Augmented Reality for Human-Robot Interaction in Industry
- Immersive Visualizations Using Augmented Reality and Virtual Reality
- Interacting with a Fully Simulated Self-Balancing Bipedal Character in Augmented and Virtual Reality
- Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
- Uncanny Valley in Virtual Reality

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Virtual Reality Applications in Education

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Synonyms

HMD: Head-mounted display; Virtual reality

Definition

Virtual Reality (VR) is a three-dimensional simulation environment where users can feel close to real life experiences in an artificial world developed with different devices and visualization equipment, as well as interacting with other objects.

Introduction

According to Gobbetti and Scaneti (1998), virtual reality is possible to create a visible world that is felt, treated, and acted on the basis of virtual reality. Similarly, Deryakulu (1999) states that virtual reality is a technology that users get different experiences from an artificial world created by computer with special technologies worn on their bodies. Sherman and Craig (2003) claim that the virtual reality environment is expressed as interactive computer simulations that allows users to immerse and simulate an environment. In the virtual reality environment, the senses act as if they perceive a physical reality (Sherman et al. 2009). Virtual reality can be characterized as either interactive or noninteractive simulation application

which is designed to create a sense of presence in a virtual world created by computer with the help of some wearable technologies and imaging equipment. Human-machine interaction in virtual reality may mislead human emotions. Dede et al. (2017) state that virtual reality focuses on visual or audio stimuli with some haptic devices and it provides sensory immersion.

Features of the Virtual Reality Environment

Three important features of virtual reality are expressed by Piemental and Teixeira (1995) as "three-dimensional graphical world," "being immersed," and "interaction." Sherman and Craig (2003) add "emotional return" to these features. According to Piemental and Teixeira (1995), the main components of virtual reality are model, computer programs, computer, location sensor, and interaction tools. Whyte (2002) states that interaction is the main feature that separates virtual reality from animation and navigation. These features are described in the following text.

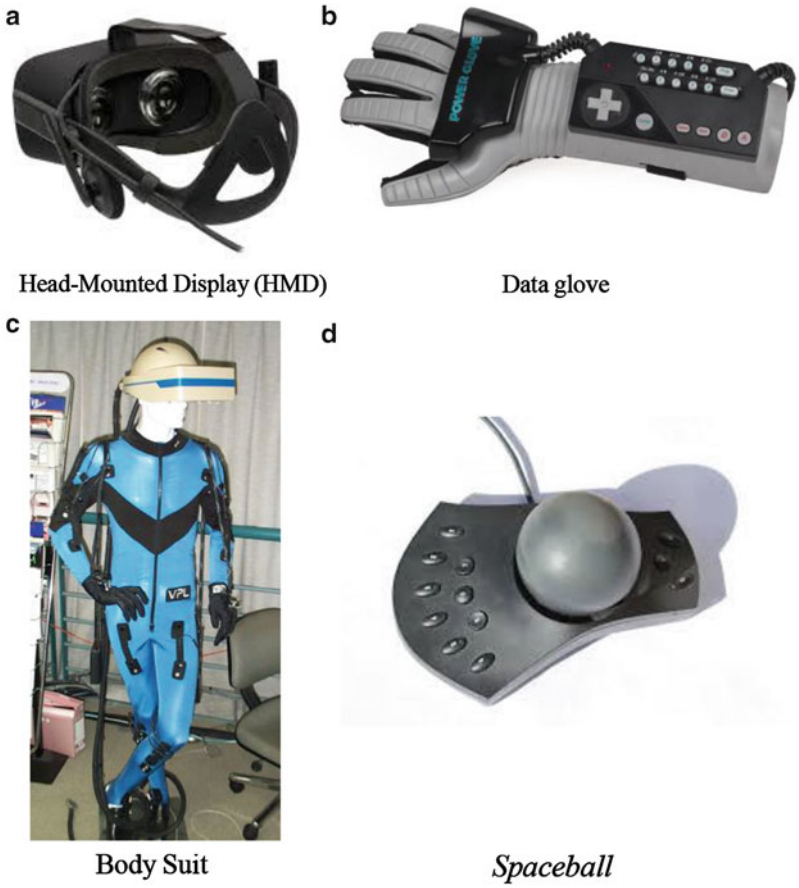
Three-dimensional graphical world: Modeling of real environment or imaginary space.
Being immersed: The fact that you are mentally withdrawn from the real world.
Interaction: The response of the environment to the user's commands.
Emotional return: To be sensibly affected by the actions of the observer in the virtual environment.

In addition Burdea and Coiffet (2003) emphasize that virtual reality has three important components ("three I"). These are: immersion, interaction, and imagination. Immersion means creating the feeling of "being there" (presence); interaction means ability of the users to move in the virtual reality environment and to interact with the objects; and imagination means convincing users to believe something even if their representation is unreal.

Types of Virtual Reality

McLellan (1996) deals with types of virtual reality under nine titles. These are defined in the following text.

- *Immersive First-Person:* The user is positioned within the view. Constant interfaces and a BOOM imager are used to simulate the experience of going through virtual space. The BOOM viewer attaches to the front of the viewer.
- *Augmented Reality:* It is an information processing technology that combines real-world images with computer-generated encoded data.
- *Desktop VR:* It is the easiest one in virtual reality. The biggest disadvantage is that the user does not feel like being immersed. This reduces the feeling of being in the environment (presence).
- *Mirror World:* This system uses video cameras as input devices. The user sees his or her own image as adapted to the screen.
- *Waldo World:* In Waldo world, user is connected to real time by a remote control mechanic router. The user controls an image of the computer animation placed on a robot or image in real time by wearing an electronic mask or body suit plugged a sensor detecting movements.
- *Chamber World:* The virtual world in this environment is defined as a room surrounded by walls and ceilings. The observer enters this place and fully adapts to the virtual world by wearing three-dimensional special goggles. This interactive virtual reality environment, potentially consisting of many users, can be used effectively in collaborative projects. The CAVE system is an example of systems installed with ceilings, floors, and screens with four walls mounted.
- *Cabin Simulator Environment:* It requires environments that are connected to computers, designed in the same way as reality. It allows the real environment to reflect on the screen and to interact with the user.
- *Cyberspace:* It is possible that anything can be found anywhere and anytime in cyberspace. Any person at any point in this world can



Virtual Reality Applications in Education, Fig. 1 Some interactive devices used in virtual reality. (**a**) *HMD*: In these systems, the position can be continuously measured with motion sensors. Once attached to the head, the current image can be viewed through the optical system. The user can easily navigate around the virtual environment (Beier 2008). (**b**) *Data Glove:* The data glove is an input device which provides data entry to computer with hand movements and specific positions. (**c**) *Body Suit:* By entering these clothes equipped with special sensors, users' movements can be perceived and user movements can be transferred to digital environment. (**d**) *Spaceball:* These devices are joystick-like and can be used by pressure in desired direction. Spaceball is also used in motion analysis

be found in the same environment at the same time.

- *Telepresence/Teleoperation:* The individual feels that she/he is in a different place than the place where she/he is physically present.

Interactive Devices Used in Virtual Reality

Interactive devices used in virtual reality can vary according to their purpose. Some of these interaction devices are introduced below. Figure 1 shows some interaction devices used in virtual reality.

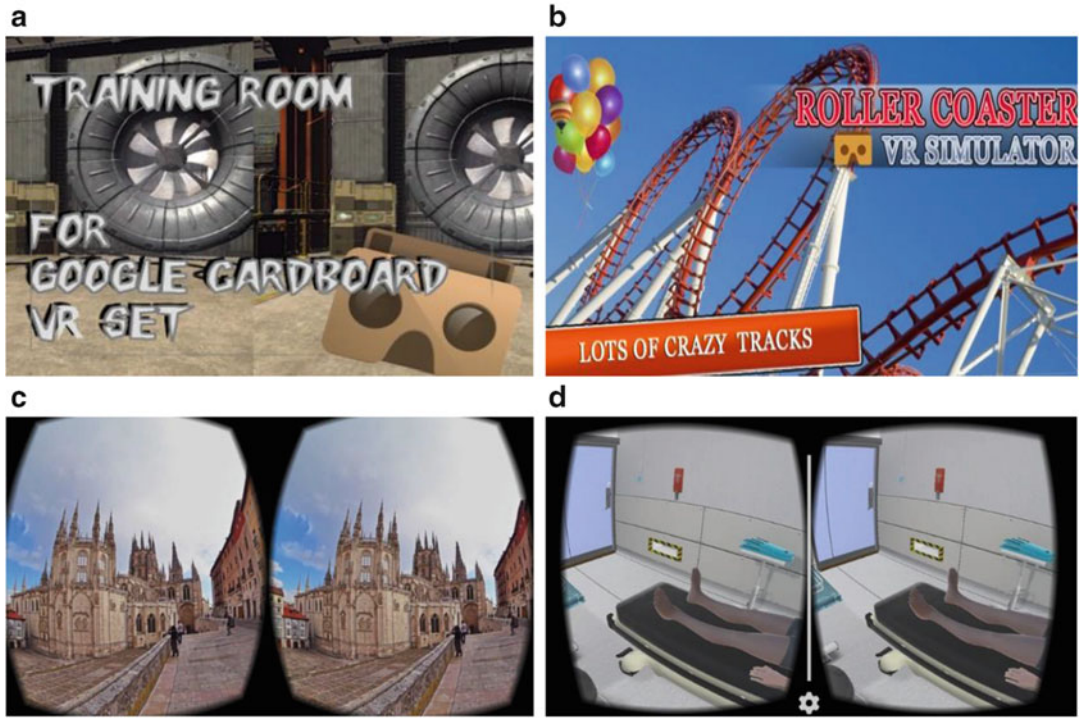
Some New Virtual Reality Technologies

The high cost of virtual reality devices, the limited access to facilities, requiring expertise in the adaptation into the education sector, and long-term use leading to health problems are disadvantages of virtual reality applications. Although virtual reality applications were seen as an expensive technology, virtual reality experience has been sought after and desired by everyone recently. Increased interest to virtual reality attracted attention of mobile technology companies, and this caused the development of numerous new mobile equipment and applications including components of virtual reality. Especially, by decreasing the cost of virtual reality goggles, virtual reality applications for mobile operating systems became accessible and practical. Many free downloadable virtual reality applications in Play Store or App Store, for example cheap Cardboard goggle (Fig. 2) developed by Google Company, became easily accessible for users.

Detailed information about Cardboard is available at https://www.google.com/get/cardboard/. With Cardboard applications, users can feel different experiences. This virtual reality goggle can be used for games (Fig. 3a), entertainment (Fig. 3b), nature trips (Fig. 3c), and medical training (Fig. 3d).

Virtual Reality Applications in Education, Fig. 2 Cardboard goggle

Another new trend in virtual reality is forming videos by jump camera system (Fig. 4). This technology offers to users the opportunity to watch 360° videos. Jump camera system consists of 16 camera modules placed in a circular pattern. Length of this setting and positions of these cameras were optimized to work with Jump compiler program. Jump compiler program converts video images consisting of 16 pieces to stereoscopic virtual reality videos. Thanks to its high-resolution stereoscopic vision technology nearby objects are perceived as nearby, while distant objects are perceived as far. In these devices, 3D alignment method specially developed and integrated into the system is used in order to obtain a seamless and panoramic image. Thus, the combination locations where the camera images from



Virtual Reality Applications in Education, Fig. 3 (**a**) Game, (**b**) entertainment, (**c**) nature trip, and (**d**) medical experiences

Virtual Reality Applications in Education, Fig. 4 Jump camera setting

Virtual Reality Applications in Education, Fig. 5 Google spotlight stories

each camera come together are not recognized. Designed 3D videos are equivalent to super high-resolution images at least five 4 K image. This technology is expected to reveal a new trend in cinema and gaming industry.

Another new technology "Google Spotlight Stories" interactive videos (Fig. 5) were designed by Google for smart phones. In these applications when sensors for videos located in certain regions were stimulated, video passes to the other stage through the sensors on smartphones. Each scene is part of the whole videos scenes and so continuity is provided in the video. Users can feel themselves in an interactive virtual reality scenario when they use it with Cardboard goggles. Today, while this application is supported by only some Android devices, support for numerous mobile devices has been recently expressed by the manufacturer.

Educational Uses and Potential Advantages of Virtual Reality Applications

Virtual reality applications can be found in the areas of entertainment, tourism, e-commerce, medicine, defense, construction, manufacturing, and education. Sala (2016) also mentioned virtual reality can be used in medical applications, foreign language acquisition, engineering training, education, field of architecture, and interior design. Students can conduct educational trips with virtual reality applications. Thus, they experience a sense of being there (presence), and they virtually go to and can hear voices of objects there. Virtual reality applications have been used in military education as defense and attack with support of simulation. In medical education, students can study on virtual cadavers or living human body and experience realistic situations. Students might have a chance to perform dangerous and costly experiments repeatedly in virtual realistic labs. Virtual reality can be effectively used to teach intangible concepts in mathematics, for better understanding of historical phenomena in history, or to teach surface formations in geography. It can also be used in the context of interacting with people in different countries for language teaching. Every user can see each other in same virtual environment and communicate and interact by using different virtual reality devices with the help online multiuser virtual reality applications. Three-Dimensional Virtual Worlds (3DVWs) are known as desktop virtual reality environments. 3DVWs can be used for

educational purposes in higher education as simulation, field trip, gaming, discussion, and virtual lecturing (Ghanbarzadeh and Ghapanchi 2016). Augmented reality is an extension of virtual reality. As in virtual reality, augmented reality applications are also used for educational purposes. Augmented reality applications can foster effective and efficient learning (Uluyol and Şahin 2016). These kinds of applications provide the fulfillment of effective collaborative work activities. Ip and Li (2015) state that virtual reality technology brings new opportunities and challenges to teaching and learning. In addition, virtual-reality-based learning environments incorporate instructional design for educational purposes.

There are some limitations of virtual reality. The costs of virtual reality applications are high, the accessibility is limited, and the expertise required for the education sector is troublesome. It is not easy to use for learners and technical information is needed. Fowler (2014) emphasizes that one of the challenges of virtual reality is understanding the pedagogical design and use of virtual reality systems. Further, virtual reality can lead to health problems during longtime usage (such as headache and eye pain). But these limitations can be overcome as the time passes and the following benefits of virtual reality applications in education may be embraced:

- Virtual reality may directly contribute to the development of students' complex ideas and skills (Roussou 2004).
- Virtual reality may offer personnel learning strategies and didactic paths that privilege an intuitive approach (Sala 2016).
- It may enhance motivation and learning (Dede et al. 2017).
- It may facilitate learning, support abstract concept learning, implement paradigms, support vocational training, support decision-making, support realization, and enhance learning process (Mellet-d'Huart 2009).
- It may be abstracted from external factors, allowing it to selectively focus on the information that is being studied.
- Virtual reality may provide a strong environment for students to understand the lesson.
- Virtual reality may enhance students' creativity and self-confidence.
- Virtual reality may provide facilities for learners when examining places where learners have no opportunity to explore.
- It may provide practice environments where it is not possible for students to experience it in real life.
- Learners may learn more effectively by joining as many applications as they want at their own pace.
- Learners may experience virtual reality by participating in applications independently of time and place.
- Students may have the opportunity to perform a task that requires physical effort and to explore as if in real life environments, without fatiguing at the computer.
- Because virtual reality environments require interaction and active participation, it may shift learners from passive to active.
- With virtual reality applications, the ability of students to use different virtual reality hardware may increase.
- Learners may learn by doing through self-discovery in virtual reality environments.
- Virtual reality environments may overcome the risk factors that can be encountered during real life events.
- Individuals with disabilities who have no chance to participate in experiments and learning environments may have access to learning experiences with virtual reality environments.
- With virtual reality applications, individuals who are far away and have common interests may come together for common projects and gain different experiences.

Cross-References

- ▶ Everyday Virtual Reality
- ▶ Virtual Reality as New Media
- ▶ Virtual Reality Systems, Tools, and Frameworks

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Virtual Reality as New Media

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Here are some of the most exciting ways in which virtual reality is new media.

Synonyms

Engagement; Experience; Immersive; New media; Real life; Real world; Virtual reality; World

Definition

Virtual Reality = A immersive computer-generated environment that incorporates auditory and visual elements. It is often interactive and it may contain sensory feedback such as haptic.
New Media = A digital form of media created, consumed, and distributed using digital devices such as computers, smartphones, and the Internet. It is often contrasted to old media such as television, radio, and print media.

Virtual Reality as New Media Is Revolutionary

Virtual reality was the favorite toy of techies and hackers looking to expand their skills and knowledge. The concept of virtual reality as a widely accessible form of media seemed quite far away, but now it is evolving to the point that it could even be used to make games on our smartphones more immersive.

Virtual reality is exciting and revolutionary. It's not only changing the way we use media but also the quality of people's lives. It's already being used in a number of different industries, from education to business and even real estate. Here

are some of the most exciting ways in which virtual reality is new media.

Smartphones

It's exciting that virtual reality has already moved from consoles to smartphones, and there is a whole line of headsets on the market already. The smartphone headsets tend to be a bit smaller than the console ones, something a little more akin to the ones that appeared in Back to the Future.

There is a huge range of apps that you can access using virtual reality, over 100 to be more precise. YouTube is one of them, allowing you to watch videos with 360-degree vision – something you may have already seen on social media advertising. There is also a range of games, from simple puzzles to ones that really show what the future of horror games and virtual reality has to offer.

Social Functions

Business functions are typically held around a table in an expensive restaurant. However, virtual reality seeks to change this. By incorporating it into social functions for business (or even leisure), you can show those you are meeting with a whole new side to you and your business.

It's easier to go through plans and documents, and it makes the whole experience much more engaging. While it could be seen as antisocial, you are all still able to communicate verbally; you just get to see more.

The Treatment of PTSD

Over eight million adults are diagnosed with PTSD each year. There are a number of causes, from childhood trauma to experiences that were had in the military. Traditionally, exposure therapy is used to treat the disorder, where patients recount and visualize their traumas in an attempt to treat it and remove the trauma.

Virtual reality uses the same form of treatment, but it offers a more realistic and visual world. The scenarios are played out on the screen, immersing the patient. They are then asked to narrate what is happening. The patient is able to stop at any time, just like in regular therapy.

Immersive Gaming

Becoming lost in our video games is one of the great escapes from reality. With the evolution of virtual reality, it is possible to become completely absorbed. The game surrounds you, and you are able to use your body to control the mechanics of the game. In many ways, it is becoming the new Nintendo 3DS or 3D TV – a mass market for new and exciting content.

So much is and can become accessible through the virtual reality systems, and it has the power to present you with everything at your fingertips, from video games that surround you and use all of your senses to access to your favorite streaming apps for watching movies and amusing online videos. The possibilities have the potential to be endless.

The Next Steps

In the future of virtual reality, we can be sure to see an increase of realism in the graphics produced for video games that use it. Much like regular console games have become more photo-realistic; virtual reality ones will likely follow in their footsteps. Along with this, there is likely to be increased interactivity, and research is already being carried out to see how this can be improved for future releases.

The continued development of content that is interesting is also something that has to be continued and constantly improved on. In terms of smartphone apps and video games, people are going to tire of the same content, and so more must be added, and it must be more interesting than the ones that came before it. Virtual reality is done gaining trust and acceptance; now it needs to start evolving.

In terms of new media, it has the potential to become one of the most used pieces of technology (New Media Film Festival). With applications in just about every industry and field (from business to medical training) (Applications of Virtual Reality), it really is the definition of new media. The future of virtual reality is incredibly bright as long as developers continue to work on

this new piece of tech and listen to the feedback they receive.

Cross-References

- ▶ New Media
- ▶ Virtual Reality

References

Applications of Virtual Reality. https://www.vrs.org.uk/virtual-reality-applications/
New Media Film Festival. http://www.newmediafilmfestival.com/

Virtual Reality Components

▶ Virtual Reality Systems, Tools, and Frameworks

Virtual Reality Development Methodology

▶ User-Centered Design and Evaluation Methodology for Virtual Environments

Virtual Reality Engine

▶ Virtual Reality Systems, Tools, and Frameworks

Virtual Reality Entertainment

▶ Augmented Reality Entertainment: Taking Gaming Out of the Box

Virtual Reality Exercise and Rehabilitation

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Synonyms

Exercise; Exergaming; Virtual reality; VR rehabilitation

Definitions

Virtual reality (VR) can be described as "a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels" (Burdea and Coiffet 2003). *Exercise* should be understood as planned physical activity, from the intention of either increased fitness or other health benefits, as opposed to the expression *physical activity*, which is to be understood as simply movement involving muscle contraction (Landi et al. 2010). *Exergaming* is an activity with games constructed around physical activity or exercise as a facilitating part of the gameplay mechanic (Wüest et al. 2014). *Rehabilitation* can be defined as "the restoration of form and function, following illness or injury" (Hoenig et al. 1997) and "restoration of an individual's capability to achieve the fullest possible life compatible with his abilities and disabilities" (Hoenig et al. 1997). VR exercise and VR rehabilitation are to be understood as any exercise or rehabilitation activities that involve VR to facilitate its purpose.

Introduction

Lots of aerobic exercise involves motion and movement across larger areas (cycling, running, skiing, etc.), and several forms of exercise are

performed in a specific environment (strength conditioning in a gym, soccer play at the pitch, etc.). The exercise environment is therefore a part of the exercise experience for many practitioners, and can become an identifier of that exercise, and can be part of what motivates a user toward the exercise activity (Gladwell et al. 2013).

Many can (theoretically) perform most exercise types, while others are limited by certain factors: specific geographical or environmental requirements, such as skiing; human physical limitations, such as periods of temporary injury; or more permanent conditions, as, for example, physical or cognitive decline with old age, permanent injury, or innate physical handicaps. These individual factors can prevent practitioners from entering the natural environment of many exercise activities. Meanwhile, virtual reality (VR) has shown to be useful in this relation, by its convincing ability to simulate aspects of real experiences in the virtual domain, experienced in some regards as if being transported to a place that convincingly appears as if it exists. This refers to one of the most defining features of VR, which is commonly referred to as the sense of presence.

The sense of presence, as described by Slater et al. (2010), is when a user responds to the experience of a virtual environment – and treats the virtual reality, as if it was real. To experience a sense of presence, there are two orthogonal components to consider (Slater 2009). The experience of being situated in the virtual environment (VE) is referred to by Slater as the place illusion (PI) (Slater 2009). Part of the PI comes from how VR may allow users to carry out actions as they would in real life and interact with the VE or virtual objects in it. The experience of a VE may also elicit user reactions or responses as they would be expected in real life (dodging while passing a branch) or experience that the VE reacts convincingly to them being in it (such as a virtual bird dodging the user). This is referred to by Slater as the plausibility illusion (Psi) (Slater 2009). An additional key component to experiencing presence is the perception of having a body inside the VE. Seeing how a body (be it your own in a cave or a virtual when using a HMD) integrates and interacts with the virtual world plays a central part in the realness of the experience (Slater et al. 2010). In this way, VR can allow users to convincingly experience places, which are out of their immediate reach (such as a wood workshop, where there is none in real reality). Or find themselves in situations which they may otherwise be secluded from (sitting at the bottom of the Pacific Ocean). VEs can also enable users to perform certain actions that are not possible in the immediately available real-world environment (e.g., building a chair in the virtual wood workshop) or even actions that would simply be impossible in real life (e.g., unassisted levitation).

VR is a potentially powerful mediation tool for both exercise and rehabilitation. The ability of VR to place (just about) any virtual context to a real-world situation or augment the experience of a real-world activity by altering the VE feedback to that action can manipulate a big part of the user's experience and redirect attention to where it is considered most useful. A virtual augmentation of an activity can amplify the impact of positive actions or remove attention from unwanted aspects. If a user considers the real-world environment demotivating for their exercise routine, an alternative virtual environment can be created, which caters to the users' motivation or the desire to exercise. If a user does not find a repetitive rehabilitation routine stimulating (lifting a 0.5 kg weight 100 times), have the VE react to each lift in a way, which effectively augments the user's experience of the activity into something completely different. The format of the virtual environments and the augmentations depends on a lot of factors, such as the user demographic, exercise or rehabilitation type, available hardware/software, etc. The following sections will address some of the ways in which VR has been utilized for exercise or rehabilitation purposes.

VR Exercise

Mood benefits affiliated with regular exercise, such as enjoyment, energy, and reduced tiredness, have shown to be enhanced when exercising using VR, to a level surpassing regular exercise (Plante et al. 2003). Similar results have been recorded

when pairing VR with biking exercise, for instance, with elderly users at nursing homes (Bruun-Pedersen et al. 2016b), which allowed the elderly to experience nature-based VEs while on an indoor exercise bike. Results showed an increase in interest and enjoyment of the activity, when measuring the intrinsic motivating to exercise. The results were based on (a) residents' enjoyment of the VE nature settings and (b) how the augmentation gave purpose to resident's biking actions (i.e., changing the perceived value of the actions). In their particular everyday life, no residents were able to bike, and very few residents were able to leave the nursing home to enjoy nature (Bruun-Pedersen et al. 2016b). VR's potential as an exercise motivator also shows as a result of the users' sense of presence and the immersive properties of the system: immersion referring to the degree of sensory stimulation perceived from the mediating technology displaying the VE (Slater 2009). Ijsselsteijn et al. showed that the increase of the immersive properties and increases in the sense of presence resulted in positive effects on exercise motivation (IJsselsteijn et al. 2006), also the case for elderly users (Bruun-Pedersen et al. 2016a). Besides its potential as an exercise motivator, VR has also shown affinity as a training tool for exercise-related skills. Rauter et al. have shown how a rowing machine, with a high-fidelity VR simulation of a rowing experience, was able to enable a transfer of rowing skills from the VR machine onto rowing sessions in the real world (Rauter et al. 2013).

VR Rehabilitation

Even if VR is a relatively new technological tool for rehabilitation and therapy, it has diverse applications (Rizzo et al. 2015). Exposure therapy in VR has been able to induce similar emotional responses with users as in reality and used in psychotherapy for the treatment of phobia, etc. (Carvalho et al. 2010). Stroke rehabilitation using VR is showing an increasing body of work (Corbetta et al. 2015), for instance, in relation to balance training (Gheorghe et al. 2015), but also VR for analgesia (for instance, in relation to burn wound treatment) has been shown to have real effects (Malloy and Milling 2010). Physical therapy rehabilitation treats problematic conditions with regular practice of controlled movement treatment, specific to the injury. These are often performed indoors in controlled clinical environment (Hoenig et al. 1997), but users and therapists may find themselves secluded from what would naturally be the optimal environment for the rehabilitation practices (Rizzo et al. 2015). For sports rehabilitation, this has shown to cause negative effects on patients' "treatment acceptability," from the sense of detachment to the context and practice which the rehabilitation should eventually enable (Brewer et al. 1994). One way to counteract negative treatment acceptability has been mental exercises including goal setting, counseling, and visualization of the end result (Brewer et al. 1994). For sports practitioners, such mental exercises naturally relate to sports scenarios and have shown to build a more purpose-oriented connection between the rehabilitation procedures and its goal (Brewer et al. 1994). Meanwhile, VR's potential to contextualize exercise activities or actions of a user is a huge leap forward from the mental exercises (Bruin et al. 2010). VR and multimodal feedback can either take users' attention away or place users' attention specifically on certain aspects of the activity or user behavior (Bisson et al. 2007) (Burdea and Coiffet 2003), onto where it is most relevant for the user experience (Holden and Todorov 2002), while being able to digitally monitor the movements from sensors and software (Rizzo et al. 2015). Certain movements critical for rehabilitation can also be guided or paced through the VE or amplified in case the user experience needs increased awareness (Rizzo et al. 2015).

However, for practitioners with more permanent conditions, where constant rehabilitation (or light exercise) is needed to remain healthy, the exercise actions often lack a direct pointer to any context or natural environment outside the clinical practice. For such rehabilitation regiments, augmenting, e.g., a monotonous exercise experience with a dynamic and extraordinary exercise environment in VR, might counteract

repetition that creates boredom, providing what can be described as "a shift from negative to positive thoughts about exercise" (Bruin et al. 2010).

Immersive VR Exergaming

Exergaming refers to the activity of playing a game which has physical activity or exercise as part of the gameplay mechanic (Oh and Yang 2010), with Konami's *Dance Dance Revolution* (DDR) as one of the frequently referenced (Smith et al. 2009). The exercise-inducing part of exergaming comes from an engaging gameplay element, which requires motion control input from the user, and typically does so in a fast-paced fashion. For well-crafted exergames, such as DDR, this results in an exercise-motivating gameplay experience for many users.

The motion control design of some exergames is catered to certain needs, such as gameplay for balance training (Wüest et al. 2014) or physical fitness (Konstantinidis et al. 2016) and aerobic exercise for older adults (Smith et al. 2009).

For exercise motivation purposes, it would be logical to consider the potential for combining exergaming and immersive VR. And it can be argued that the concepts of immersive VR and exergaming can be naturally connected, for instance, by their implicit need for unconventional and movement-based control schemes. Martel and Muldner argue that proper control scheme design is essential to a VR experience and impacts player experience, performance, and sense of presence (as defined by Slater) and must be considered carefully according to its intended context (Martel and Muldner 2017). Conventional control methods using keyboard and mouse pose similar problems for exergames and VR applications alike, possibly breaking exercise sequences or similarly hindering a sense of presence in the VE, in order to push buttons. In fact, one of the potentially big advantages for the combination of exergaming in immersive VR would be the merge between the contextualization of the user's actions (e.g., simulating a real-world situation fitting for the exercise actions), gameplay elements, the motion controls with (ideally) any relevant body part, and the immersive aspects of the system.

Meanwhile, this may also be what partly limits immersive VR exergaming as a genre. Shaw et al. suggest the five main challenges currently faced by exergaming (Shaw et al. 2015). And to a large extent, these mirror the challenges the VR industry faces in general: (a) motion sickness, (b) accurate motion controls, (c) appropriate view for the player, (d) health and safety risks from motion controls while wearing a HMD, and (e) feedback latency (Shaw et al. 2015). None of the points are trivial to work with in isolation, and the combination remains quite complex at this stage.

Perhaps as a result of this, only few immersive VR exergames are currently released (to the knowledge of this author). "Astrojumper" uses a three-wall stereoscopic projection setup for an immersive experience, where the player uses his/her limbs to throw green laser beams and fight a UFO attack (Finkelstein et al. 2011). Lately, more commercial products (such as BOXVR for the Oculus Rift) are surfacing, using the Oculus Touch controller for virtual hand movement in various boxing-related games. The VirZOOM bike controller has users pedal and steer under various (gaming) circumstances in VR, including simultaneously riding and catching horses with lasso or (pedal) racing an F1 car. Meanwhile, current VR exergames remain very simple. They appear premature in both gameplay and production, when considering contemporary games and VR applications, and this might remain, until the challenges from Shaw become more properly addressed.

Future Challenges

Perhaps due to the relative novelty of the technology, the definitions of which role VR has in a therapy context are seeing debate, from both a practical and a terminological perspective, for instance, discussing whether VR therapy can be called therapy if "VR technology" is not

autonomously performing therapy and rehabilitation (Levac and Galvin 2013). Similarly, the patient-therapist interaction with VR technology is novel in many cases (Christensen and Holte 2017). Patients (e.g., elderly) without previous experience with VR might not elicit confidence in the technology as a trustworthy, therapeutic device. Meanwhile, Ijsselsteijn et al. argue that precisely older adults are receptive to new technology, provided they understand the benefits of the technology for their individual purpose (Ijsselsteijn et al. 2007). Part of the patients' belief and understanding depends on the level of proficiency and confidence in the system by the therapist (Levac and Galvin 2013). Moreover, the therapist also needs to be able to naturally incorporate the VR application into the rehabilitation procedures, as with any other therapeutic practice (Christensen and Holte 2017).

Using VR for rehabilitation may be a daunting paradigm shift for some therapists and a natural step forward for others. It is mainly up to the collaboration between researchers/developers and therapists/patients to document and enable the method as well as possible.

Cross-References

- ▶ Accessibility of Virtual Reality for Persons with Disabilities
- ▶ Augmented Reality Entertainment: Taking Gaming Out of the Box
- ▶ Gamification and Serious Games
- ▶ Mindfulness, Virtual Reality, and Video Games
- ▶ Natural Walking in Virtual Reality

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Virtual Reality Game Engines

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Synonyms

Game development; Game engines; Gaming; Programming; Software; Tools; Virtual reality

Definitions

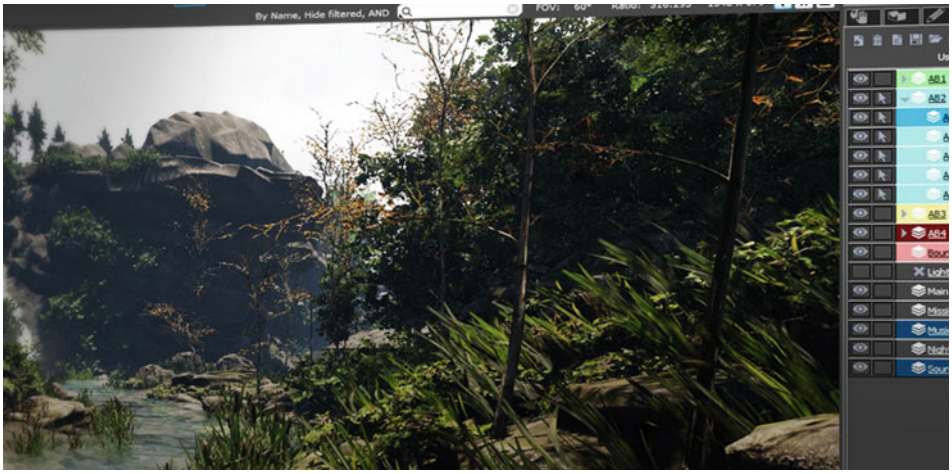
With virtual reality use cases and applications booming in the entertainment industry, filmmakers, producers and game developers alike are jumping on the bandwagon of sourcing out for the most applicable, useful and at times open-source tools for their specific virtual reality development needs. While popular brands Unity and Unreal Engine dominate the virtual and augmented reality development scene, alternatives and upcoming game engines are equally prevalent as options for game developers and virtual reality enthusiasts to explore and build their projects upon.

Introduction

Different Types of Virtual Reality

Ever since the acquisition of the virtual reality (VR) startup Oculus by Facebook in 2014, VR has experienced a comeback like no other, with various types of digital output becoming classified as VR. However, much like anything else when it comes to technology and reality, even virtual reality and its niches fall on a spectrum. Today's VR use cases have been broad; from a fully-immersive virtual reality experience rendered and viewed through the lens of a virtual reality headset (tethered or standalone devices) to an actual immersive room – otherwise known as the cave automatic virtual environment (CAVE) – virtual reality is broad as it is narrow in terms of its users, market appeal, and output. VR is currently popular in the video games and entertainment industry, alongside architectural visualizations and military simulations (the latter having been around even before 2014), either as a passive substitution of the user's environment – as in watching an immersive film – or an interactive and experiential tool for users, much like a video game or remote operating system that allows users to communicate in virtual space.

This entry will focus on exploring the multitude of game engine options available for virtual reality developers when it comes to creating



Virtual Reality Game Engines, Fig. 1 Snapshot of the CryEngine game engine interface

interactive or gamified virtual reality experiences and projects.

Virtual Reality in Games

The most commonplace use case for VR has always been in the gaming industry, and it is no surprise that gaming takes the forefront of such developments due to the industry's natural disposition to be more risk-inclined and experimental. Since the inception of VR into the gaming world, new niches and definitions of what it means to be gaming have also been formed. The term comes to mean more than just entertainment and the alleviation of boredom, to the exploration of new senses, sights, and sounds in an immersive interactive environment.

At this point of writing this entry, the two of the most common game engines being used for VR game development purposes are Unity and the Unreal Engine game engines. This entry will attempt to shed some light on other options for the purpose of gaining a more comprehensive overview of all options and tools that are available for any developer's use. The analysis would simply be a broad cross-comparison between these options for beginners and enthusiasts willing to explore these options.

Alternate Game Engines

CryEngine V

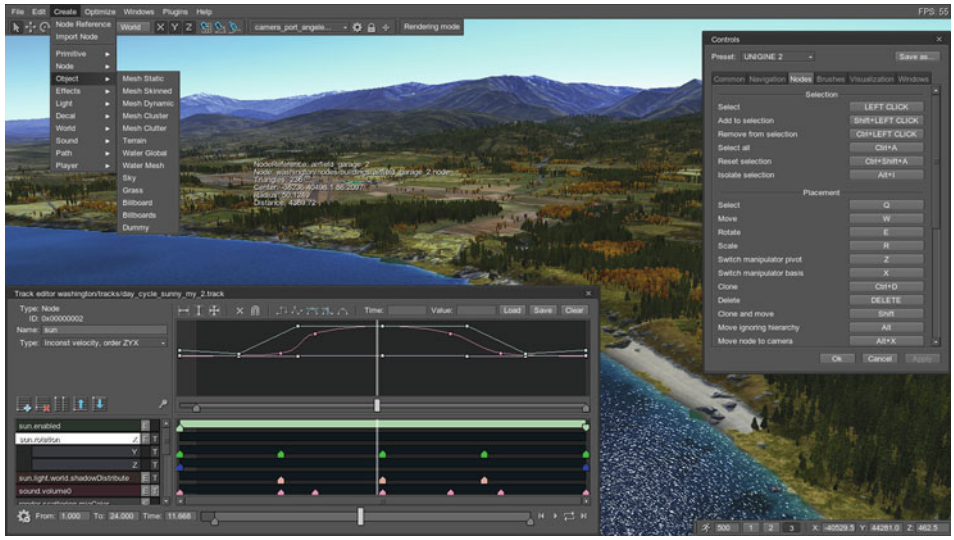
For the developers or enthusiasts hailing directly from the gaming development world, CryEngine is no stranger to anyone and has a huge pre-built following for its released CryEngine V game engine based on the fact that Crytek (the company) already has a strong base of existing users. Given that notion, it is expected that they would most likely have more developer support, tutorials, and features (Fig. 1).

CryEngine V – Cost

Since the release of this game engine under the "Pay What You Want" revenue model, the game engine is absolutely free, if the user chooses it to be so, but donations are also possible if desired. If one would like additional training, consulting services and access to more accelerated learning, one would expect to pay for and select between different tiers of CryEngine's Insider Membership packages.

CryEngine V – Pros

- Much like Unity and Unreal, CryEngine V also has a marketplace for developers to access thousands of assets and exchange them between members of the community.



Virtual Reality Game Engines, Fig. 2 Snapshot of the Unigine game engine interface

- As a VR game engine, it supports PlayStation VR, OSVR, HTC Vive, and Oculus Rift – almost every major VR hardware out there.
- Reasonable amounts of documentation (at least as much as it could offer for VR development at this point) and some support from the community (active and up-to-date) – though expect less activity than Unity and Unreal
- GPU-based particles and cloud systems (less impact on the developer's CPU).
- Contains about 75+ official tutorials on how to use the game engine.
- Games developed with CryEngine are 100% royalty-free, regardless of profits.

CryEngine V – Cons

- Apart from its official tutorials, there is limited external support and tutorials on CryEngine that is up-to-date as it would require time to accumulate the amount of support since its initial launch in 2016.
- Comparatively less users and developers to Unity and Unreal, which would likely result in less solutions and answers to be found for programming or development issues due to the smaller pool of users.

CryEngine V – Interesting Notes

It is both C#- and C++ – friendly. One would have to create a project first before downloading the game engine. They also have an initiative known as "VR First" to encourage academic institutions to create VR labs on their campuses – this is a good option to consider, for faculty members of institutions seeking to expand beyond the standardized tools of Unity and Unreal.

Unigine

Known as the professional VR platform for business, there are rarely any interface snapshots of Unigine let alone buzz or discussion about its use and how the game engine works. Mainly designed for business-to-business (B2B) markets and for industrial visualizations, and traditional virtual reality systems and use cases like scientific research and military simulations, it is possible that this game engine has had such a low profile that most developers have never heard of it, and thus never considered this option. Either way, here is a quick overview of what the Unigine game engine entails (Fig. 2).

Unigine – Cost

To get started with Unigine, one might begin with the free trial or pay the cost of the "Starter Single"

package. It is assumed that the cost of the "Sim" package would be about the cost of the individual license, plus. Regardless, all demos could be requested. Much like anything else, the more expensive the package, the more available support for one's projects.

Unigine – Pros

- One of their claims is that they offer support beyond VR to other types of immersive output as well – including CAVE systems (basically a VR system that is physically built like a cave) and curved screens.
- For B2B, it offers lots of technical support that seems to be highly customized and personalized to the business' needs – this is good for individualized attention to one's own business needs.
- Based on the visuals and screenshots on their site, they appear to have the systems capable of delivering on their promise of highly realistic VR and experiences.

Unigine – Cons

- A downside is the B2B nature of Unigine, which might also shed some light as to why most of its information is secured and locked off from public eyes.
- Less active of a community and forum – a developer's best bet for answers is going to be directly from the professional team themselves.
- Thus far, it would appear that they only have Oculus Rift support – depending on one's business, this might or might not be sufficient (checking back in for updates on any additional hardware support might be necessary).

Unigine – Interesting Notes

Their authorized distributors come mainly from Asia but they have a sales office in the United States. Due to the nature of the company and product, Unigine could potentially contain some elements that might be overlooked due to its B2B nature and highly secured information.

Fabric Engine

Somewhat of an oddball, Fabric Engine emphasizes its easy-to-use nature for artists, in-betweeners, and programmers alike using a visual programming system similar to that offered by Unreal Engine. Formed by a technical team in Canada, they go beyond just support for Fabric Engine, to include external 3D software tutorials as well.

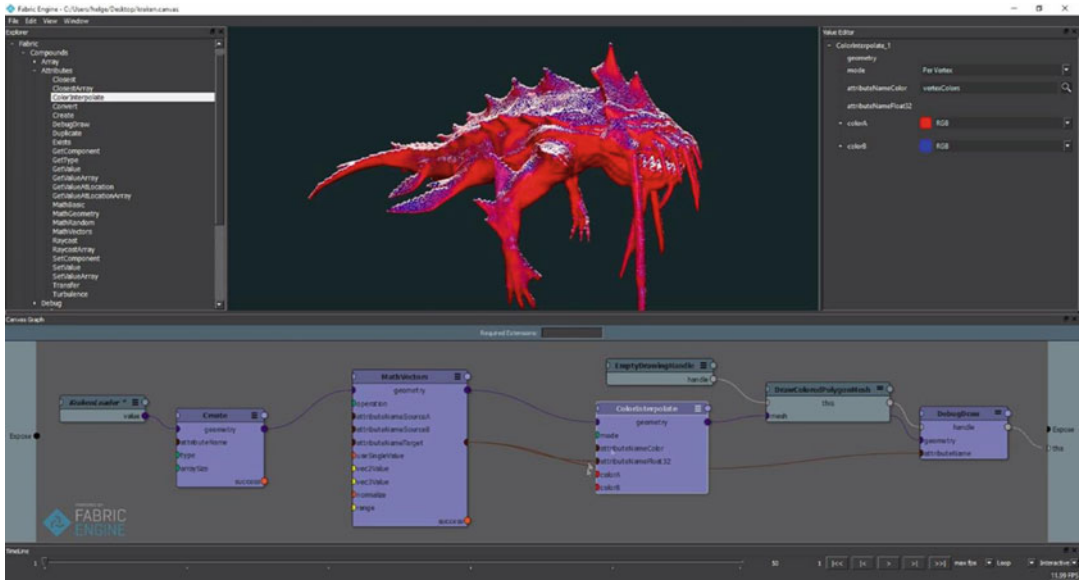
There was a downloadable version of the Fabric Engine, which held a certain degree of promise due to its node-based interface (similar to that of the Unreal Engine) and its clean layout. Unfortunately, as of this entry, their game engine is no longer being developed (Fig. 3).

Fabric Engine – Cost

Prior to the cessation of the Fabric Engine, an individual license would have cost (there was no free trial), with an extra fee to be paid for support and maintenance within the first year of purchase. If one were to rent the use or license of the game engine, that cost drops down significantly to a number more affordable to the independent game developer or user. They also offer studio and team packages at higher costs, with the possibility of a negotiable "Unlimited" package including an unlimited number of licenses. An educational license is available but one has to go through their request form.

Fabric Engine – Pros

- A massive collection of official tutorials on the engine, and even on other non-Fabric Engine related tools, are available.
- Technical documentations including step-by-step guide – telling developers exactly which and what buttons to push, with visuals, verbatim. It also tells one why that step or button has to be pushed, which helps to shorten the learning curve tremendously.
- Uses an entirely different programming language known as KL. KL has some features that optimizes memory, multithreading among other aspects, that C++ lacks or fails in comparison.



Virtual Reality Game Engines, Fig. 3 Snapshot of the Fabric Engine game engine interface

- It supports HTC Vive, Oculus Rift, Leap Motion, and Razer Hydra – quite a broad range of options.

Fabric Engine – Cons

- As with an independent or non-mainstream game engine, they have less of an active support community among fellow developers; however, it does not mean that their support from staff is any lesser in quality.
- Uses an entirely different programming language known as KL but it can call C or C++ libraries – depending on the skills of the developer, this can be a massive con.
- VR integration could still be improved.
- They are no longer in development as of the writing of this entry.

Fabric Engine – Interesting Notes

The company, Fabric Software Inc., was founded by a very technical team, which might explain some of its software features among other aspects. However, the reason it is in this list is that this might have been a potentially worthy game engine to explore had it still been in development. Major visual effects studios such as MPC and Psyop uses Fabric Engine for their film and television projects, which gives this game engine the industry validation and endorsement coming from major players of the visual effects industry.

Current Developments and the Future

Amazon Sumerian and Others

As with any technology, software or hardware, it develops quickly and changes rapidly. Since the writing of this entry comparing these alternate game engines, there have been new developments in the field resulting in other tools or software that could be useful to game developers in virtual reality.

One such example would be Amazon's Sumerian and Lumberyard software. Amazon Sumerian, launched in late 2017 for preview and experimenting, completely bypasses the programming and development process – further democratizing VR development accessibility by allowing even nonprogrammers and users with no background or experience in development or graphics generation to partake in creating their own VR, augmented reality (AR) and 3D applications and projects. With its addition of libraries of 3D characters and models, as well as its claim

to be able to run on multiple VR platforms such as the Oculus Rift, HTC Vive, and mobile, Amazon Sumerian is poised to upstage Unity and Unreal in terms of being more easily accessible and usable to the everyday person.

Amazon Lumberyard (launched in 2016), a more advanced tool in comparison, is the more serious version of Sumerian as well as an actual game engine where similar tools found in both Unity and Unreal Engine are available – including a node graph, timeline, and all other necessary features typically found in any other game engine. Their ties to gaming communities such as Twitch and Amazon's own strong web infrastructure are deliberate to allow game developers to not only develop games but also transition to and capitalize on distribution and potential showcase efforts of their VR projects thereafter.

Conclusion

Game Engine Selections

Ultimately, it depends on one's personal preference as to the software to be used in VR development for games. Given the heavy focus on VR and AR development today, one has many options to choose from, with game engines as optimized and customized for all kinds of interactive project development, including use cases such as 3D projects, games, and even live-action. The possibilities are endless and developers are definitely spoiled for choice. To avoid analysis paralysis, one should always focus on the mission and intention of the VR project.

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Virtual Reality Gaming

▶ Augmented Reality Entertainment: Taking Gaming Out of the Box

Virtual Reality Proton Beam Therapy Unit: Case Study on the Development

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Synonyms

Medical education; Proton beam therapy unit; Serious games; Virtual reality

Definition

Virtual reality facilitates a more comprehensive stage for conveying knowledge. By immersing an individual into an ultra-realistic setting, a user is able to learn about a subject by living it rather than only hearing about the topic.

Introduction

Virtual reality (VR), traditionally used in gaming, is moving into more mainstream activities and developing in focused areas such as healthcare (Sik-Lanyi 2017), for example, to help hospital patients and support training of hospital staff. Sector-based organizations are starting to recognize the benefits that VR offers toward improving the productivity of their services. As such, the main idea behind this article is to build a virtual reality proton beam therapy unit to support cancer patients undertaking proton beam therapy and, in doing so, improve the productivity of the treatment process.

According to Cancer Research UK, one in two people born after 1960 will be diagnosed with some form of cancer during their lifetime (Cancer Research UK Press Release). Children (usually classed as ages 0–16 in the UK National Health Service) make up for 1% of cancer cases in the UK, with 1 in 500 children being diagnosed each year, equating to 1,800 new child-cases per year (Cancer Research UK Press Release). The two new proton therapy centers in the UK allow for the treatment of different types of cancers. The proton beam treatment involves laying on a bed/platform inside a large spherical machine for a prolonged period. Radiation is directed directly toward the tumor cells to destroy them. It is particularly a beneficial approach for treating children. The technique moves away from the traditional cornerstone radiotherapy approach, which risks destroying surrounding tissue to the cancerous cells producing further illness and nausea. Yet, despite the benefits offered by the proton therapy units, cancer treatment is still an overwhelming process. Children are generally allocated 2-hour time slots to receive the treatment; but often this time is spent encouraging an understandably scared child to enter the large machine for treatment and remain still. The time spent encouraging the child often means that the treatment time is lost due to the child's refusal to enter the machine or that the whole treatment process is missed for that session. Therefore, developing virtual reality applications that can support cancer patients, particularly young children, is beneficial to both the patient and the hospital. The ambition behind this work is that children between the ages of 3 and 11 use the application to be adequately mentally prepared for the treatment process.

The VR development process involved in undertaking this case study requires that we work with a building information model (BIM) of a proton therapy unit. As such, a pipeline of the BIM to VR process is also outlined in this article alongside the development of the application.

Development Pipeline

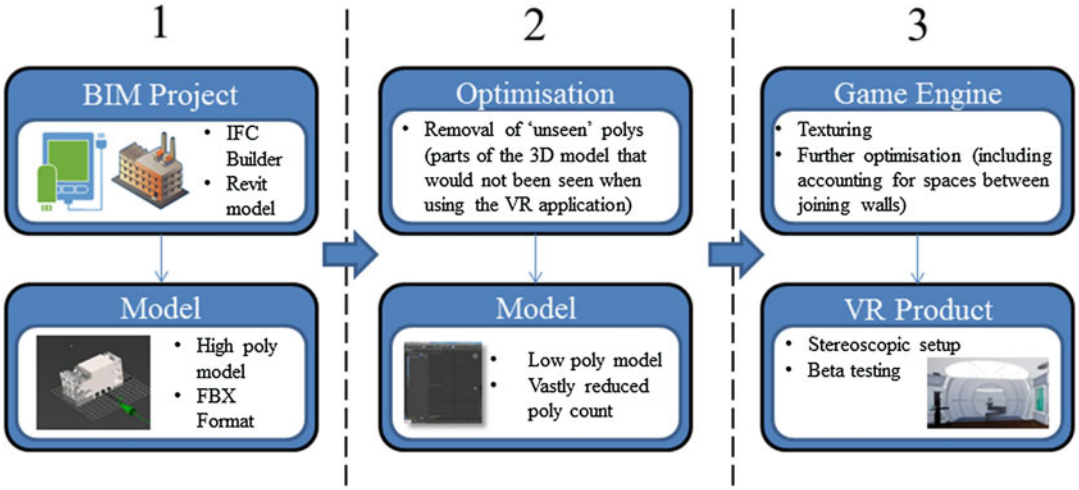
Based on a BIM model, the features of the proton beam therapy unit VR application are created with the help of Unreal Engine. In the game mode, the user is able to navigate the scene and carry a panda teddy bear in their hand and it around the room. The pipeline for the construction process is outlined.

Pipeline

The VR development follows three stages: (1) BIM construction, (2) 3D model optimization, and (3) game engine implementation. This would be a typical pipeline for a BIM to VR model in an industrial setting, as outlined in the pipeline displayed in Fig. 1.

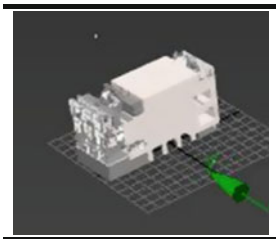
BIM Process

The BIM process is complex and involves multiple stages to refine the model through the use of hardware and software tools. BIM is concerned with the construction of every aspect of the built asset into a highly detailed 3D model recreation of the real-world object or building. It is a process which is frequently used to recreate real-world buildings and 3D models of urban environments



Virtual Reality Proton Beam Therapy Unit: Case Study on the Development, Fig. 1 BIM to VR pipeline adopted for this case study. The stages have been simplified for presentation in the figure

Virtual Reality Proton Beam Therapy Unit: Case Study on the Development, Table 1 Detailed model



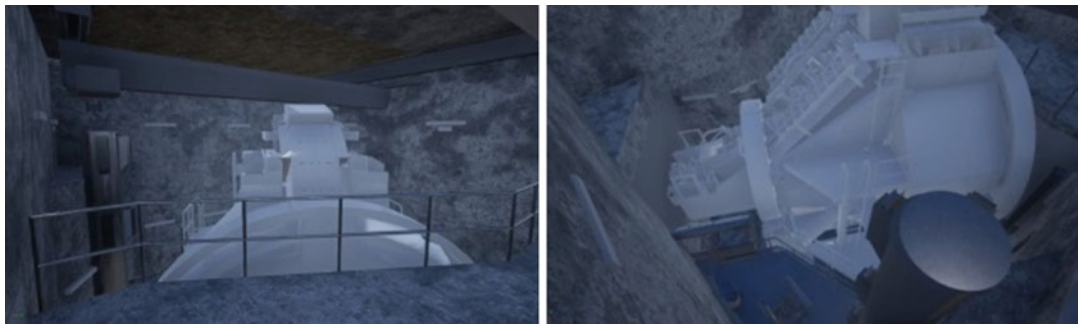
Polygons	4, 929, 163
Vertices	2,920,592
FPS	13.813

but can also be used to model the digital elevation of terrain. Typically, BIM models are constructed from point cloud data. Point cloud data is created using 3D scanners. Its application is being increasingly used in the artifact reconstruction domain (Gonzalez-Delgado et al. 2014; Cosido et al. 2015). The main challenge involved with the BIM model construction is that it results in a highly detailed model. For example, the BIM model used in this project is comprised of close to five million polygons, as displayed in Table 1. This is unsuitable for VR deployment, as the polygon count prevents the animation/game from rendering at a playable speed.

Optimization

The optimization process governs the refinement of the model into a format and polygon count size that is suitable for deployment into a game engine for VR.

For example, the BIM proton treatment unit model is comprised of thousands of individual models and details that are not needed to be present in the final VR application and can therefore be removed. Users of the application only need to see the main therapy room, therefore superfluous models (such as the rear gantry or pipework) are removed. Figure 2 displays the rear gantry, stairs, and engineer access of the proton treatment machine, which is removed during the optimization process. The optimization process can be laborious. The procedure is done by hand and requires that the model be checked through in details for removal of the superfluous 3D models. In some cases simple pipe constructions are comprised of up to 300,000 polygons. Similarly,



Virtual Reality Proton Beam Therapy Unit: Case Study on the Development, Fig. 2 Gantry and rear stair case, removed from 3D model

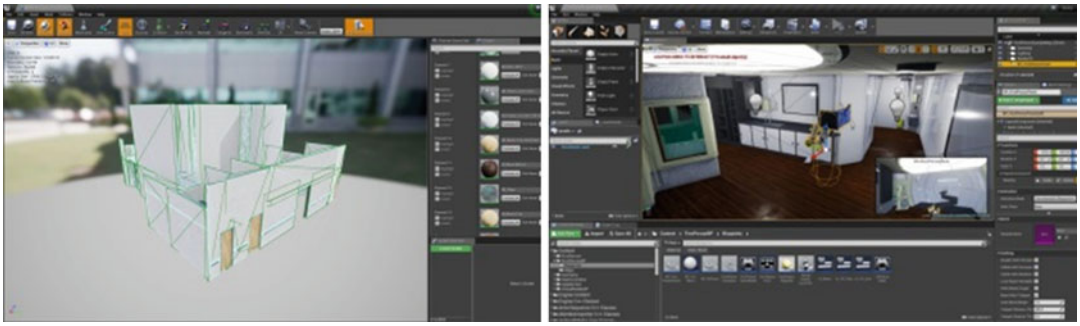
Virtual Reality Proton Beam Therapy Unit: Case Study on the Development, Fig. 3 Low poly-render of the proton therapy unit treatment room

chairs, tables, and screens consist of thousands of polygons per model. Each object and model within the scene is either replaced by remodeling the object to an object with a much smaller polygon count or removed completely from the scene. Figure 3 displays the low poly-interior of the scene following the optimization process.

Game Engine

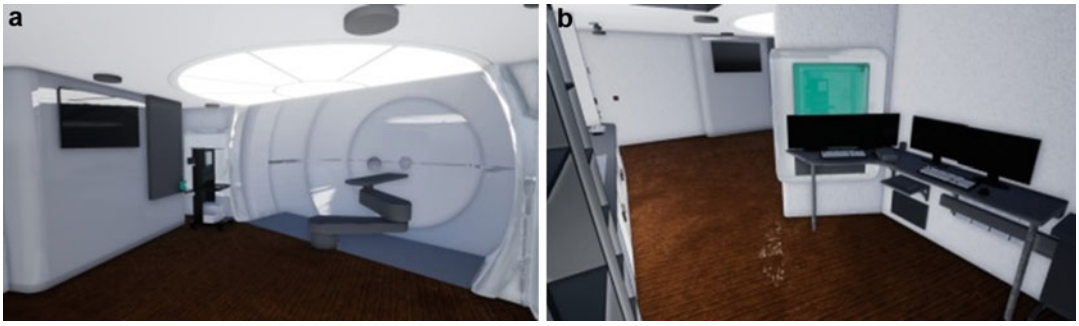
The VR application is developed with Unreal Engine and can be played either through haptic interaction, such as keyboard/mouse, or by the use of a stereoscopic viewing device such as a HTC VIVE (Fig. 4).

Using Unreal Engine 4, the .FBX model is imported into the project, allowing it to be placed into the in-game world. Here it is possible to add convex collision to the model to constrain the user to a given area and provide them with a navigable experience, without the risk of them clipping or falling through the environment. When a model is imported from an Autodesk package, Unreal identifies that there is either several meshes within the file that have individual textures or when a mesh has several textures applied to it – this is referred to as "elements." Elements allow the developer to create materials either based on given textures within the model or procedurally create new materials using Unreal's material editor to produce high-quality visuals. Unreal provides developers with a wide array of standard player components, which allow for the developer to quickly create player characters to allow the player to navigate the environment with. The standard player character includes capsule component to provide the player pawn with a collision volume, a camera



Virtual Reality Proton Beam Therapy Unit: Case Study on the Development, Fig. 4 Unreal engine development process

Virtual Reality Proton Beam Therapy Unit: Case Study on the Development, Fig. 5 Virtual proton beam therapy unit in Unreal Engine after the texturing process



Virtual Reality Proton Beam Therapy Unit: Case Study on the Development, Fig. 6 Virtual proton beam therapy unit. (**a**) Displays the treatment machine and (**b**) displays the control for the staff and technicians

component to allow the player to view the world from the pawns perspective, a mesh component to give the pawn an identity, and a movement component to allow players to navigate the virtual world with the pawn. Once development is complete, the game is packaged, which involves creating a staging folder, specifying any blueprints or levels to package, and then compiling it all into

a single executable application. The final render is displayed in Figs. 5 and 6.

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Virtual Reality Retailing

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Synonyms

Virtual reality; Retailing; Interactive design; Virtual shopping; Virtual retailing; Marketing; Virtual trial

Definitions

Virtual reality retailing (VRR) refers to the interactive virtual experiences that a retailer provides for its customers by the aid of virtual reality applications.

Introduction to VR

Virtual reality (VR) consists of immersing an individual in an imagined or replicated virtual three-dimensional world that provides ques on multiple sensory levels.

VR History and Early Examples

Despite the concept has been around since early 1960s, it took some time for VR to take attention from the public. Morton Heiling was the first to take action in exploiting the possibilities in moviemaking with his patented *Sensorama* that included a vibrating seat with a scent emitter to provide a richer 3D film experience (Drummond et al. 2014).

Contemporary VR Market

However, it was not until virtual reality company Oculus was bought by Facebook in 2014 for $2 billion that the VR finally started to attract the long-deserved attention (Solomon 2014). Moreover, predictions about VR market range from $30 billion by year 2020 to $45 billion by year 2025 (Li 2016; McKone et al. 2016; Weinswig 2016).

Virtual Reality Retailing (VRR) Market

Retailing is amongst the sectors that lead the expected high growth. Virtual reality retailing (VRR) is expected to reach some 32 million users in retailing by year 2025 (Bellini et al. 2016) with its anticipated applications either in-store or out-of-store (McKone et al. 2016) depending on physical presence of the customer.

VRR Examples

Some early adoptions of virtual reality retailing involve the virtual house tour by the luxury

home auctioneer Sotheby's (Bellini et al. 2016); the virtual viewing experience of appliances, paint, patio furniture, tools, flooring, and home décor by Lowes for redecoration; the virtual outdoor sporting experience by recreation brand North Face (Li 2016); virtual kitchen viewing as well as gamified store openings by IKEA (PYMNTS 2017a); virtual car showroom experience by Volvo (Robertson 2015); virtual furniture viewing by e-retailer Wayfair; virtual property preview for incoming guests by Airbnb (PYMNTS 2017b), shopping for virtual objects by Swarovski (PYMNTS 2017a) with payments enabled by Mastercard (PYMNTS 2017c), enhanced e-shopping experience by Alibaba (CNBC 2016) . Some retailers are believed to complement their stores with VRR to benefit from the attractiveness of sci-fi effect.

Key Concepts of VR Crucial to the VRR Success

VR often features common elements in offering an immersed virtual experience (Zhu et al. 2017). Head-mounted displays (HMDs) that are similar to snorkeling goggles in shape and size to restrict the wearer's field of vision only to the screen involved in the glasses are the most common element. This is followed by some platform that would run the video content on HDM. Computers, smart devices, tablets, and game consoles could be named among these platforms. And lastly, the dynamic experience in the virtual world is possible through some input from the individual by head tracking or controllers. A major challenge for VRRs is to provide an easy to use, brand-relevant, frank experience for their consumer by the aid of these common elements (Vrechopoulos et al. 2009).

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Virtual Reality Stereo Post-Conversion After Effects Workflow

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Synonyms

After Effects; Conversion; Postproduction; Software; Stereo; Stereoscopic; VFX; Visual effects; Virtual reality; Workflow

Definitions

Prior to the developments of The Foundry's Nuke CARA VR interface and plugins as well as Adobe's increased developments and integration with third-party tools today for live-action virtual reality postproduction, stereoscopic virtual reality was considered a difficult undertaking for independent virtual reality filmmakers and artists alike to achieve due to costs, lagging postproduction tools, or the issues that came with stereoscopic virtual reality filmmaking with stereoscopic camera equipment. Virtual reality stereoscopic post-conversion in the most easily-accessible postproduction software After Effects was necessary as a first step for complete beginners to the virtual reality filmmaking world to easily follow a step-by-step postproduction workflow to convert their monoscopic virtual reality footage from a simple virtual reality camera rig to stereoscopic 3D virtual reality footage.

Introduction

Different Types of Virtual Reality

Ever since the acquisition of the virtual reality (VR) startup Oculus by Facebook in 2014, VR has experienced a comeback like no other, with various types of digital output becoming classified as VR. However, much like anything else when it comes to technology and reality, even virtual reality and its niches fall on a spectrum. Today's VR use cases have been broad; from a fully-immersive virtual reality experience rendered and viewed through the lens of a virtual reality headset (tethered or standalone devices) to an actual immersive room – otherwise known as the cave automatic virtual environment (CAVE) – virtual reality is broad as it is narrow in terms of its users, market appeal and output. VR is currently popular in the video games and entertainment industry, alongside architectural visualizations and military simulations (the latter having been around even before 2014), either as a passive substitution of the user's environment – as in watching an immersive film – or an interactive and experiential tool for users, much like a video game or remote operating system that allows users to communicate in virtual space.

This entry will focus on exploring the passive form of VR that is live-action virtual reality and the production and rendering of panoramic videos, an art form more commonly referred to as cinematic virtual reality.

Shooting Stereoscopic VR

Prior to the software and tools we have available today that can easily work with the increasingly-accessible customizable VR camera rigs for both stereoscopic (stereo) and flat (nonstereoscopic) virtual reality footage, during the earlier years of the second rising of virtual reality back in 2015, these tools were nonexistent. Perhaps even today, these tools are out of reach to the everyday filmmaker and VR enthusiast who wishes to explore the live-action VR medium in stereoscopic 3D.

While it does ease the process of postproduction and editing when capturing footage using a stereoscopic VR camera rig such as that of the Google Jump VR camera rig, the footage would still require manual adjustments and fixes in postproduction. These fixes include the need to address broken depth due to unexpected stitching results in postproduction or even the complete upheaval and restitching and compositing of certain segments of the footage. Usually, this process of restitching and compositing of patches of corrected stereo footage would require high amounts of processing, rendering, and wait times

that could severely delay the independent filmmaker's workflow and production pipeline.

Postproduction Stereoscopic Conversion

One could anticipate that by the time that this entry has been published, newer tools, techniques, and technology will have been released to counter the workflow that is to be discussed in this entry, but the purpose of this workflow process outlined is not to tout its viability in lasting through the highly iterative and constantly changeable nature of technology per se but to serve as an option for independent filmmakers who are looking to get into virtual reality, with little to no budget – as well as the enthusiastic developer who might be able to take this process one step beyond how it presently works.

This pipeline was first established and implemented at a virtual reality startup the author was involved in, during their early days where the only tool they had at their disposal that they knew how to use was the Adobe Creative Suite. Not only does postproduction stereo conversion offer a more democratized alternative to the hardware and software solutions presently available, but it also gives the independent VR filmmaker more control over the look of their stereo VR footage – a feature that is normally irreversibly baked into captured stereo VR footage.

The images and snapshots used in this entry are taken from the company's publicly-released reel and the shot is not the property of the author – they are merely used for the illustration of the postproduction workflow of stereo conversion for VR.

The Workflow

STEP 1: Cleanup Seams

Beginning with the obvious – one would first need to cleanup the stitched output. In fact, before one even does any stereoscopic conversion, all of the VR panoramics (panos) should already be polished, cleaned, fine-stitched, and composited to remove all artifacts and seams. As one could tell from the above image, there are no seams or artifacts whatsoever, and that is the ideal starting image you would want to use to begin your stereoscopic post-conversion work (Fig. 1).

In order to cleanup the seams, an artist could accomplish this either in After Effects, Photoshop, or a combination of both. If the artist is a high-skilled compositor, Nuke or a node-based compositing software would be in the artist's arsenal of tools; for everyone else, this workflow will be outlined using After Effects.

Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 1 Final output of a clean, artifacts-less VR panoramic still frame

STEP 2: Import Fine-Stitched (Clean) Output into After Effects

Import the shot into one's compositing software of choice.

Ideally, if the artist has access to this software, one would want to use The Foundry's Nuke as it is more suitable for stereoscopic compositing, editing, and conversion (not considering its current availability of tools and plugins for VR compositing).

STEP 3: Intense Rotoscoping

The purpose of rotoscoping (or commonly known as "masking" or "roto" for short) is to isolate and create the layers of stereo depth one wishes to add into the scene. Alternatively, the more masks used, the cleaner and more polished the roto is, as one would have more control over certain areas of the character or element in the shot. In this example, the lady is being separated from the background, which will be treated as a separate layer in z-depth (third dimensional depth and space). The additional masks over the strands of hair are mainly to have a more polished and controlled roto of the character (Fig. 2).

This will be the most time-consuming part of all of VR stereoscopic post-conversion, next to waiting for the renders of any VR stereo panoramic image.

STEP 4: Clean-Plating

Stereo post-conversion creates artifacts as it now creates empty spaces or gaps in a shot that began as a flat monoscopic image.

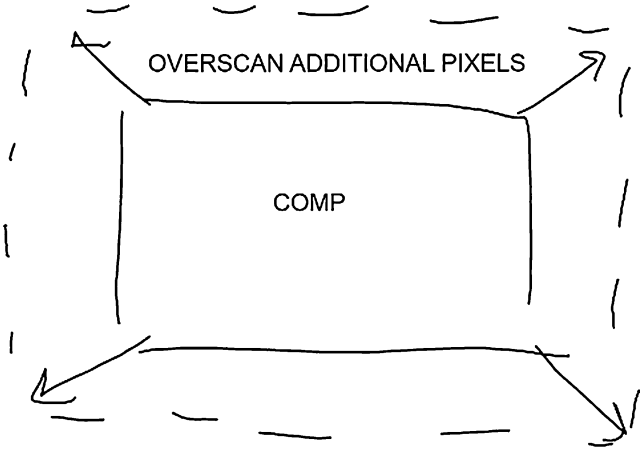
To address this, different and multiple layers of clean-plating would be necessary to fill those gaps (Fig. 3).

The quick sketch above shows the concept of clean plating – the idea of which is to extend or contract portions of the footage or film plate that would then conceal those stereo artifacts.

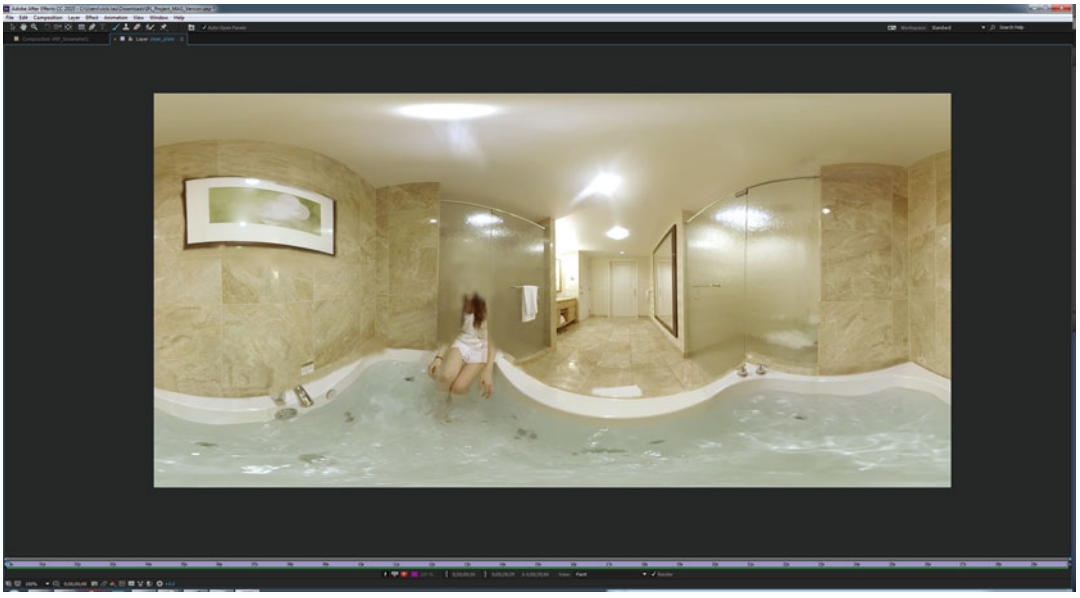
Ideally, one would have shot a clean plate (with no actors, moving elements or anything of that sort) but if this is not an option (or forgotten), a clean plate would have to be created.

To capture a clean plate on-set, one would essentially leave the camera rig rolling for about 30–60 s (longer if there are any active or moving background elements) to capture a "clean plate"

Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 2 VR panoramic work-in-progress showing rotoscoping progress



Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 3 Illustration of the creation of additional pixels of leeway for clean plating



Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 4 VR panoramic clean plate example

(no actors, no animals, preferably no moving elements) of the set (Figs. 4 and 5).

Depending on how many layers of stereo depth the filmmaker desires, one would have different finishing levels of clean plates in terms of the areas that would have extended or contracted when they were first created in the artist's design editing software of choice. In this example, the plan was to separate the bath tub and the picture frame on the wall; thus, the clean plate was contracted by painting in its surrounding pixels.

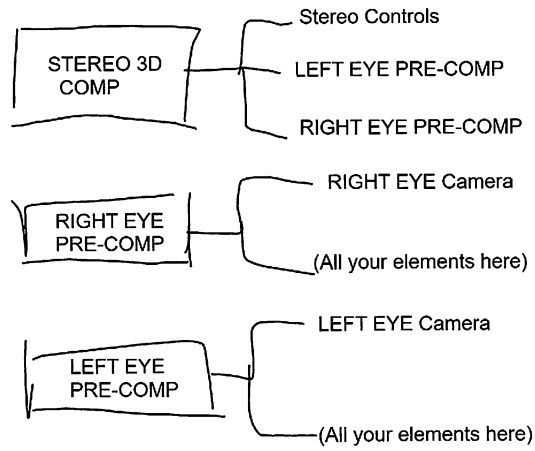
It is important to note that the deeper and more exaggerated the intended stereo depth effect, the more paint work and clean plate extension or contraction one would require to pull off the effect.

STEP 5: Precomps and Layering

The purpose of precompositions (precomps) is to ensure that the shot's depth layers do not leak into other layers. Invariably, this step could be implemented at any point in time during the VR

Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 5 VR panoramic work-in-progress showing the clean-plating contraction progress

stereo conversion process even after the stereo 3D rig has been set up; to avoid doing double work, precomps are best set up at this step of the process. Essentially, one would create a precomp (parented with other rotoscoped elements or not) of each layer of element to be stacked and layered in z-depth and space; in this case, the precomps or parented layers would be as follows: girl in tub, picture frame, and background (Fig. 6).



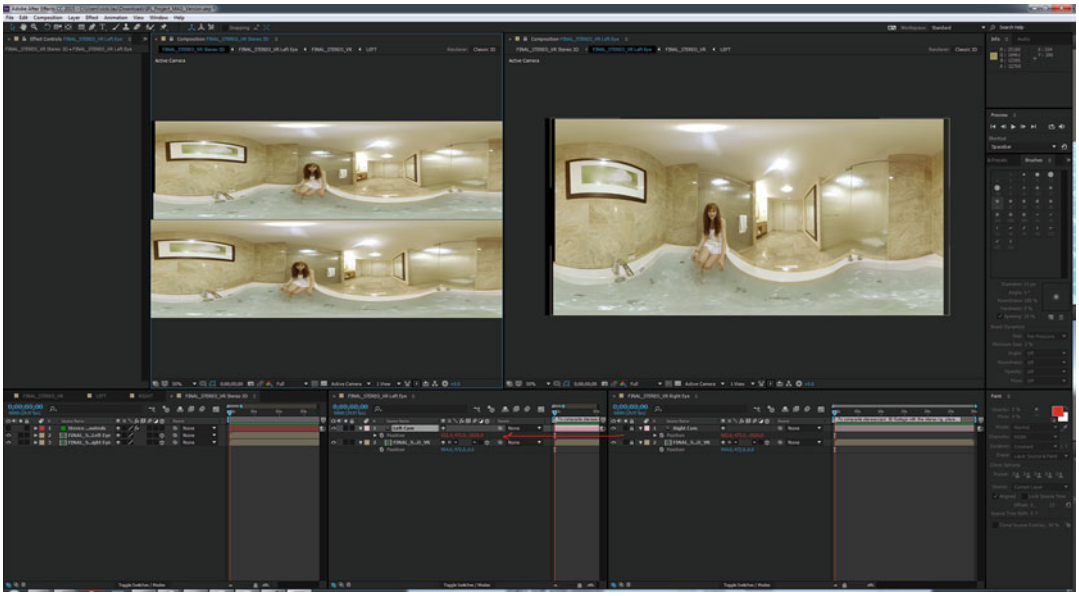
Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 6 Illustration of the hierarchy of precompositions in After Effects to simulate stereo depth

STEP 6: Create Stereo Camera Rig

After the completion of the rotoscoping process, creation of necessary clean plates, and layering of elements in z-depth accordingly, one would then proceed to create a stereo camera rig (a packaged plug-in that comes with After Effects by default). This can be found in After Effects via the following menu items: Layer → Camera → Create Stereo 3D Rig. Once created, this would open up stereo control tools for the artist to handle the amount of stereoscopic convergence and distance one would like to have in the scene. One would have to experiment with the values in Stereo Scene Depth, Convergence Z Offset, and Scene Convergence on a shot-by-shot basis as this solution has to be adapted to each shot creatively, depending on the stereoscopic effect intended (Fig. 7).

The Master Cam layer generated by the Stereo 3D Rig in After Effects is not necessary and hence deleting that will not be an issue.

One would want to ensure, however, that the 3D View is set to "Over Under", and that a split-



Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 7 VR panoramic work-in-progress showing the implementation of the After Effects stereo camera rig

screen workspace has been set up as seen in the image above – ideally outputting to a stereo external monitor (in full resolution) in order to interactively review any real-time results on the screen (whilst wearing polarized glasses).

STEP 7: 3D Layers and Depth Stacking

Setting this up is only the first step – one would now dive into one of the precomps (recommendation is to start working in the precomp for the stereo "Left Eye") and start blocking out the elements in z-depth. To prevent double work, one can parent or link the position values from the pre-comp for the stereo "Right Eye" to its respective layer elements in the stereo "Left Eye," such that any elements adjusted in z-depth would move simultaneously in both right and left eye precomps (Figs. 8 and 9).

The sketch above is a top-down 3D view of what these layers might look like with depth stacking.

The designated red area would be the furthest stereo depth layer (in this case, the room/background) while the other layers are pulled to the front to make them "pop" off the default convergence plane of the background (Fig. 10).

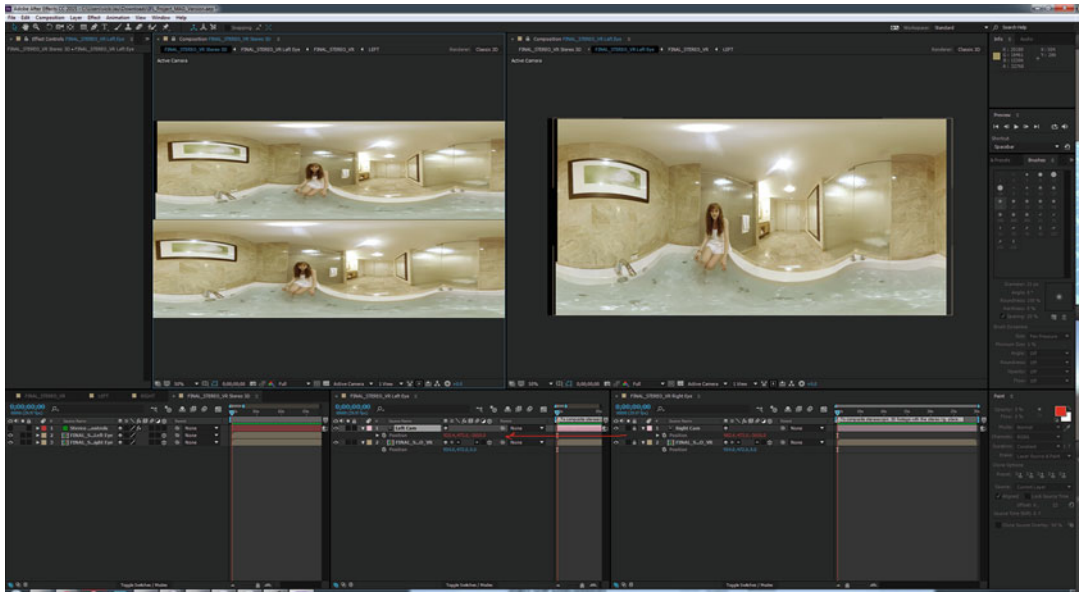
In After Effects, the more negative the z-position values, the more it tears off the screen. The more stylized and heavy the intended stereo effect is, the more work is involved in the creation of the clean plates.

STEP 8: Prepare for Oculus or Gear VR Output

This is the final step before exporting the "over-under" stereo composition (comp) to be played back in the VR device of choice. However, depending on the amount of convergence set in the existing composition, one would notice two bars of black in both the "Left Eye" and "Right Eye" comps (Fig. 11).

There are many ways to address this – either by cheating the scale or having an overscanned and extended clean plate of the background in place. For simplicity's sake, one might consider cheating the scale in its width. To prevent the disproportionate outcome, one could play around with the entire composition's scale itself to counter the altered aspect ratio.

Once that is done, simply export the highest level (main composition) of the "Stereo 3D Comp" in the appropriate format and that should be it. Take note that the export doesn't have to be a

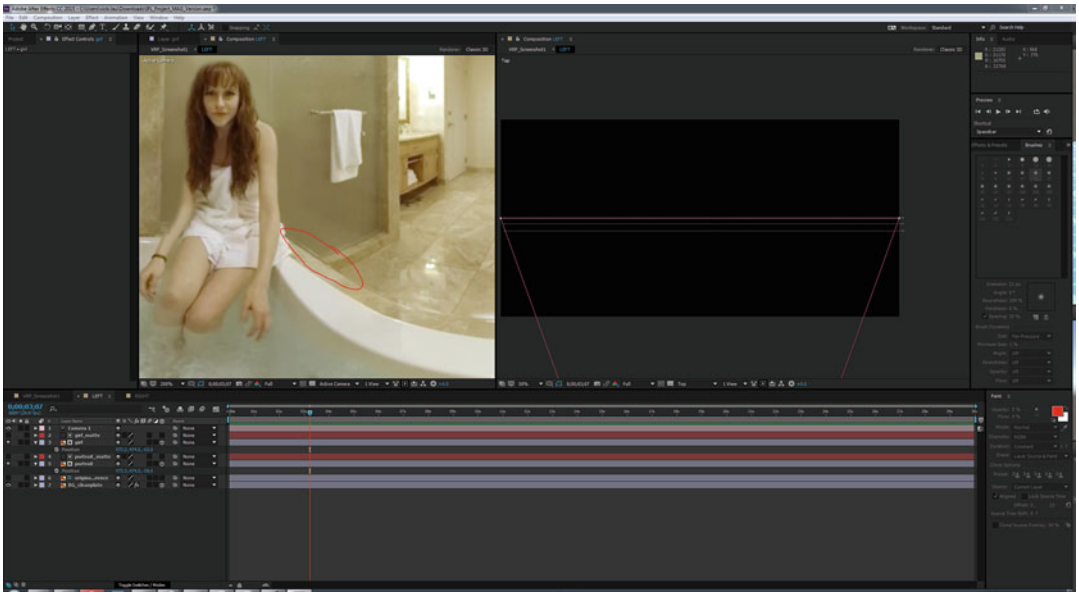


Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 8 VR panoramic work-in-progress showing the stereoscopic workspace layout

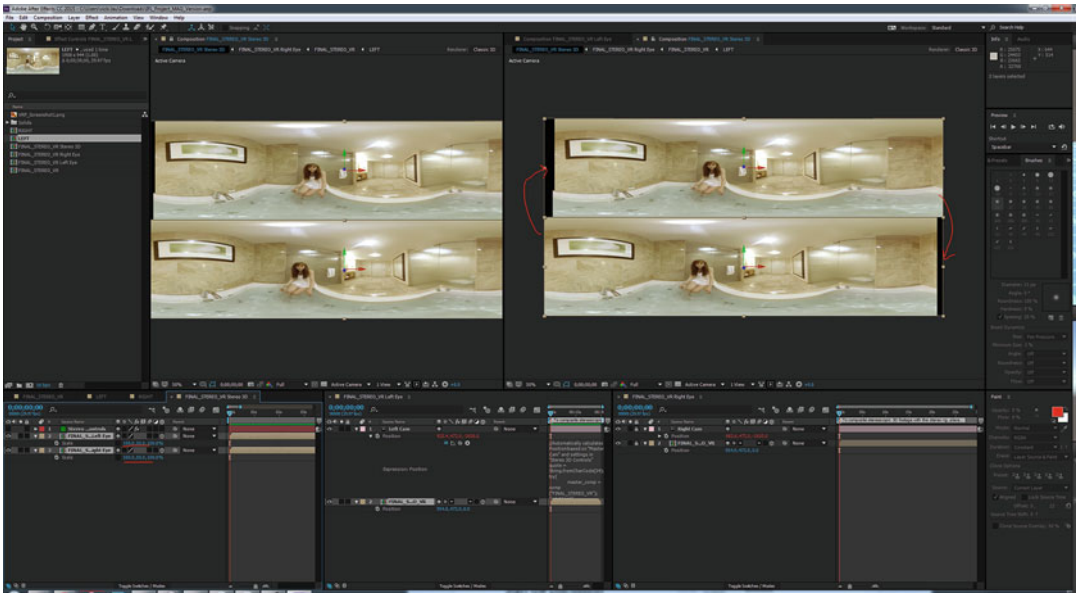
Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 9 Illustration of the hierarchy of precompositions in After Effects to simulate stereo depth

2 K by 2 K square, as it has been tested that the pixel qualitative differences between a 2 K by 2 K export and a 2 K by 1 K export would not be discernible enough to the naked eye. At the same time, the VR device should instantaneously stretch your output to fit the viewing area, regardless of its incoming resolution size (Fig. 12).

To conclude, this entire process is actually a derivative process from the visual effects world known as dimensionalisation. In fact, it was once a first, rudimentary step in visual effects attempts to create stereoscopic 3D images by converting monoscopic pictures to stereoscopic. If one did heed the advice above in this entry, this technique is already outdated in the visual effects 2D motion picture world, as many better techniques are now around (which includes proper depth maps, warping, and other tricks that deserve their own exploration separate from this entry). However, if



Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 10 VR panoramic work-in-progress showing the layers in z-depth space and being pulled off the flat image



Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 11 VR panoramic work-in-progress showing the black vertical bars in both stereo comps

a pseudo-stereo effect is all that the independent VR filmmaker is after, given the small boutique nature of the filmmaker's VR start-up or one-man show, give this a shot.

The real truth behind this simple workflow for live-action VR content is that there is no "secret sauce." Just lots of tedious, hard work – and a bit of recycling of existing visual effects tricks.

Virtual Reality Stereo Post-Conversion After Effects Workflow, Fig. 12 Final output of a clean, artifacts-less stereoscopic VR panoramic still frame from After Effects

Current Developments and the Future

Today's VR Stereoscopic Tools and Plugins

Speaking of visual effects and trickery, returning back to today's available tools for stereoscopic VR, The Foundry is currently at the forefront in terms of developing tools for today's filmmakers and artists seeking to develop cinematic virtual reality – albeit at a price.

CARA VR is an example of such a development by The Foundry that integrates with their compositing software Nuke, for the purpose of creating, compositing, and polishing captured VR footage, stereo or otherwise. Rather than a lengthy post-conversion process however, CARA VR's toolset simply allows you to stitch and modify monoscopic or stereoscopic VR footage. In other words, although the independent filmmaker would have an easier time modifying VR footage, they would still have less control over the depth intentions in their VR footage.

Moving from Nuke back to After Effects, Mettle's "Skybox" plugin is another example of a development for stereo VR in the postproduction world, where developers and companies are slowly catching up with the increased demand driven by independent filmmakers' interest in exploring both flat and stereoscopic cinematic VR.

Even today's stereoscopic camera rigs are much more accessible, with numerous options, compared to a time, not too long ago, when only GoPro cameras were available with such rigs.

Conclusion

The Nature of Workflows

Ultimately, the nature of workflows is simple – they are always changeable and subject to the demand of the artist and end-user. In the case of the above outlined stereo post-conversion workflow, it shall always serve as an option for the budget-strapped VR filmmaker until newer and better systems and processes have been democratized for the masses with regards to converting flat VR footage to stereo.

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Virtual Reality System Fidelity

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Synonyms

Immersion; Realism

Definition

System fidelity is the degree with which real-world experiences are reproduced by an interactive system (McMahan and Herrera 2016).

Introduction

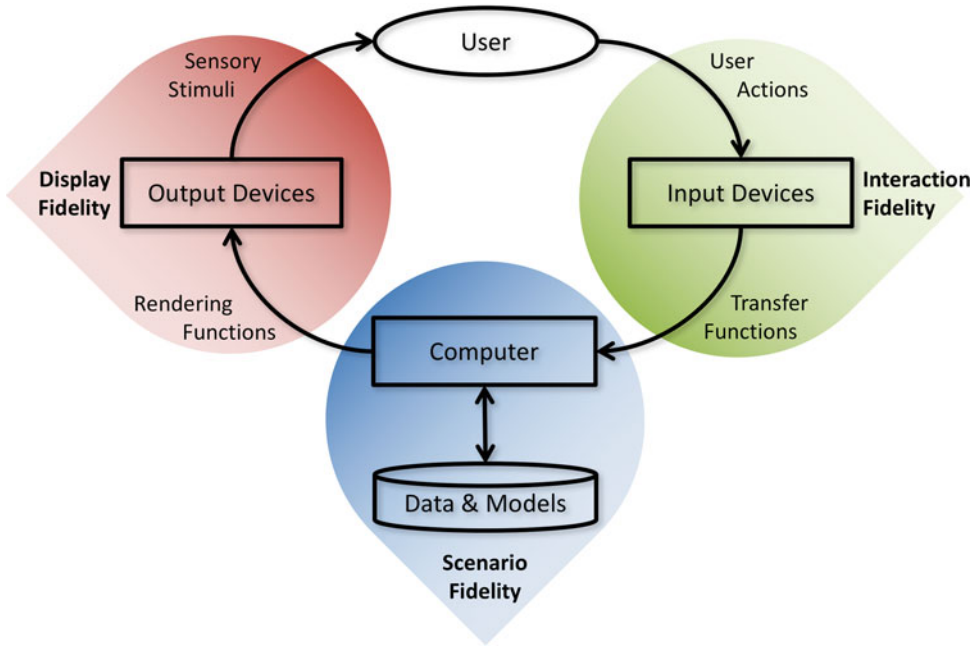
Virtual reality (VR) uses tracking devices, simulations, displays, and other technologies to immerse the user in a synthetic, spatial world seen from a first-person point of view that is under the real-time control of the user (LaViola et al. 2017). Many VR applications have been developed to provide realistic experiences by emulating the real world, such as phobia therapy, military training, and entertainment (Bowman and McMahan 2007). However, the efficacies of these emulated experiences are highly dependent upon the application's implemented system fidelity.

System fidelity is the degree with which real-world experiences are reproduced by an interactive system (McMahan and Herrera 2016). It is a well-structured, hierarchical concept that is defined by the flow of information that occurs when a user interacts with a system. Consider the user-system loop, depicted in Fig. 1. As the user performs actions that manipulate or are directly captured by input devices, transfer functions translate the inputs into meaningful operations. The fidelity of these user actions, input devices, and transfer functions characterizes the system's *interaction fidelity* – the degree with which real-world actions are reproduced in an interactive system (McMahan et al. 2012). How the simulation's data and models determine the outcomes of the meaningful input operations characterize the system's *scenario fidelity* – the degree with which rules, behaviors, and environment properties are reproduced in a simulation, as compared to the real world (Ragan et al. 2015). Finally, the resulting state of the simulation is rendered to the system's output devices, which produce the sensory stimuli that character the system's *display fidelity* – the degree with which real-world sensory stimuli are reproduced by an interactive system (McMahan et al. 2012).

This entry reviews the various qualities and effects of each subcomponent of system fidelity.

Interaction Fidelity

Interaction fidelity describes how realistically users interact with a system compared to the real-world situation that the system is emulating. As depicted in the user-system loop, interaction fidelity depends on the user actions, input devices, and transfer functions that are involved when interacting with a system. The Framework for Interaction Fidelity Analysis (FIFA) defines three major categories of system aspects that influence interaction fidelity (McMahan et al. 2016): biomechanical symmetry, input veracity, and control symmetry.



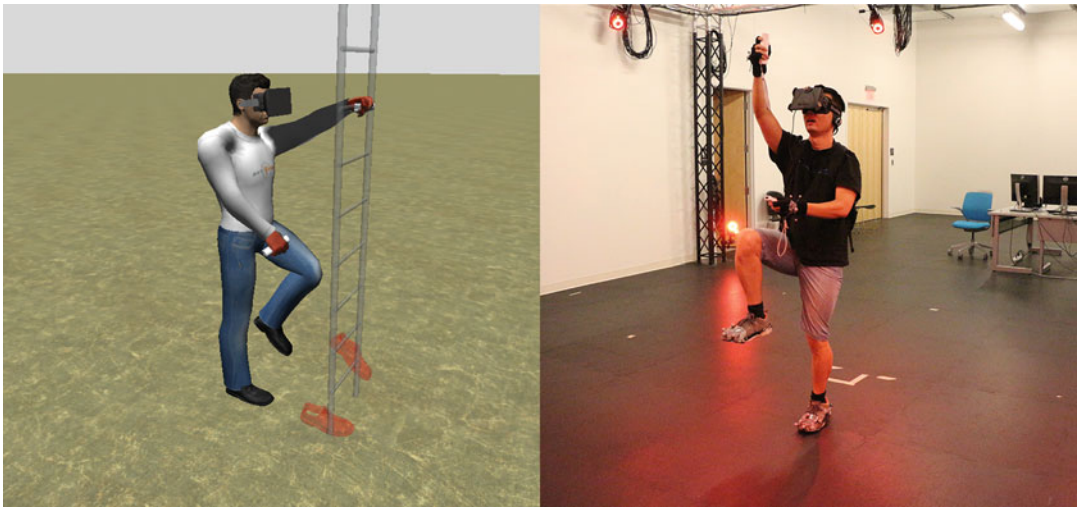
Virtual Reality System Fidelity, Fig. 1 The user-system loop depicts the flow of information in an interactive system. The three subcomponents of system fidelity are also indicated: interaction fidelity (green), scenario fidelity (blue), and display fidelity (red)

Biomechanical Symmetry

Biomechanical symmetry is the degree with which real-world body movements for a task are reproduced during interaction (McMahan et al. 2016). It can be characterized by the *anthropometrics* (i.e., body parts), *kinematics* (i.e., motions), and *kinetics* (i.e., forces) required by an interaction technique. Consider, for example, the March-and-Reach technique (Lai et al. 2015), in which the user must move both hands and both feet to climb a virtual ladder, in comparison to merely grabbing the rungs of a virtual ladder (Takala and Matveinen 2014). The March-and-Reach technique affords more biomechanical symmetry due to requiring more anthropometric symmetry (i.e., the legs) and more kinematic symmetry (i.e., leg motions). See Fig. 2. However, both techniques afford little kinetic symmetry due to missing the external supporting forces provided by the physical ladder rungs in the real world.

Input Veracity

Input veracity is the degree with which the input devices capture and measure the user's actions (McMahan et al. 2016). The input veracity of a system is dependent upon three subcomponents: accuracy, precision, and latency. *Accuracy* refers to how close an input device's reported values are to the "true" values that it is attempting to measure. On the other hand, *precision* refers to a device's ability to reproduce the same results with repeated measures. For example, in a consumer VR system, such as the HTC Vive, the accuracy of the system is indicated by how close the virtual representation of a handheld controller is from the physical controller, while the precision is indicated by the stability or lack of jitter in the virtual representation when the physical controller remains still. Finally, *latency* is the delay between user input and the sensory feedback generated by the system in response to it (McMahan et al. 2016). In consumer VR systems, expected latency ranges between 16.7 ms (60 frames per second) and 11.1 ms (90 fps).



Virtual Reality System Fidelity, Fig. 2 The March-and-Reach technique affords a high degree of biomechanical symmetry to climbing a real-world ladder

Control Symmetry

Control symmetry is the degree with which control in a real-world task is provided by an interaction (McMahan et al. 2016). It depends solely on the *transfer functions* that translate user input into meaningful interactions. For example, a simple virtual hand technique, which directly maps the six degrees of freedom (6DOF) of a handheld tracker to the user's virtual hand, provides a high degree of control symmetry to manipulating real-world objects with one's physical clinched hand, which also affords 6DOF. On the other hand, a ray-casting technique, which manipulates virtual objects with a 2DOF virtual ray at an offset, provides a lower degree of control symmetry.

Effects of Interaction Fidelity

Interaction fidelity has been shown to have significant effects on user performance and user experience. It has been shown to significantly impact performance in manipulation tasks (McMahan et al. 2006) and travel tasks (McMahan et al. 2010). It has also been shown to significantly impact presence (i.e., the sense of "being there"), engagement, perceived usability, and even strategies employed by users (McMahan et al. 2012). However, many of these results indicate that increased interaction fidelity is not necessarily better. In fact, interaction fidelity has been referred to as the "uncanny valley" of VR due to the U-shaped curve produced by mapping levels of interaction fidelity from various studies to their resulting user performances (McMahan et al. 2016). Users' lack of familiarity with mid-fidelity, seminatural interaction techniques is considered the primary reason for this U-shaped curve of the effects of interaction fidelity (McMahan et al. 2016).

Scenario Fidelity

Scenario fidelity describes how realistically the simulation's data and models represent the real world. It depends on the rules, behaviors, and properties of the simulation. These can be categorized as physical coherence, behavioral coherence, and attribute coherence.

Physical Coherence

Physical coherence is essentially how logical and consistent the physics of the simulation are to the real world (Skarbez et al. 2017). Examples of high physical coherence would be a virtual desk supporting a virtual lamp placed on it or a virtual door rotating open when its handle is pulled.

However, there are common examples of poor physical coherence, such as the user walking through a virtual wall or not being able to manipulate a small object within reach.

Several factors affect physical coherence. *Colliders* define how the physics engine (if there is one) will treat a virtual object during collisions. For example, developers will often use box colliders to represent objects to reduce the overall computational requirements of the simulation. However, these box colliders may result in lower physical coherence (e.g., a virtual soda hovering above the opening of a virtual trash can). Once a virtual object is under the influence of the physics engine, there are several physics-based factors that will influence its physical coherence: *mass*, *center of mass*, *gravity*, *velocity*, *drag*, *angular velocity*, *angular drag*, etc. Another factor for physical coherence is the concept of using *constraints* that restrict the movements of objects to certain degrees of freedom, such as restricting virtual travel to the horizontal plane (LaViola et al. 2017).

Behavioral Coherence

Behavioral coherence is how logical and consistent the behaviors of virtual agents (e.g., virtual humans) within the simulation are to the real world (Skarbez et al. 2017). Virtual agents that realistically respond to the user's actions afford high behavioral coherence, while more simplistic agents may fail to realistically respond, hence reducing behavioral coherence.

Behavioral coherence depends on three simulation aspects, like the Model Human Processor (Card et al. 1986): the agent's perceptual model, cognitive model, and motor model. The agent's *perceptual model* defines the information that the agent will make decisions based on. Perceptual models can be quite complex and include aspects such as the simulation state, the spatial properties of objects and agents, the properties of human users, and the spatial properties of the virtual world for path planning (Rickel and Johnson 1999). The agent's *cognitive model* defines how the agent will generate decisions and actions based on the information from its perceptual model. There are four basic types of cognitive models, each with increasing complexity: simple reflex agents, model-based reflex agents, goal-based agents, and utility-based agents (Russell and Norvig 2016). Finally, the agent's *motor model* is responsible for mapping the decisions of the agent into observable events, such as body movements, facial expressions, and speech (Rickel and Johnson 1999) (Fig. 3).

Virtual Reality System Fidelity, Fig. 3 Behavioral coherence depends on the virtual agent's perceptual, cognitive, and motor models in order to realistically interact with the virtual environment and the user

Attribute Coherence

Attribute coherence is how logical and consistent the attributes of virtual objects are to the real world. The factors that primarily affect attribute coherence are the object's mesh representation and material. While a high-polygon *mesh representation* (i.e., the set of polygons that represent the 3D surface of an object) will yield high attribute coherence, it can also negatively impact the simulation's frame rate and, ultimately, the system's display fidelity (Bahirat et al. 2017). Meanwhile, an object's *material* defines the texture maps, colors, and numeric values that will be used to render the object's mesh representation. If an object's material is well crafted, the object may be perceived as having high attribute coherence, despite a possibly low-coherent mesh representation.

Effects of Scenario Fidelity

Like interaction fidelity, scenario fidelity can have significant effects on user performance and the user experience. Physical coherence, particularly constraints, has been shown to improve user performance for various manipulations and travel tasks (LaViola et al. 2017). Behavioral coherence (e.g., the motor control of an agent's gaze) has been shown to significantly impact the perceived plausibility of a simulation (Bergström et al. 2017). Similarly, increased attribute coherence (e.g., mesh representations and materials) has been shown to increase the perceived plausibility of a simulation (Skarbez et al. 2017).

Display Fidelity

Display fidelity describes how realistically the sensory stimuli produced by the system resemble the real world. It depends on the rendering functions, output devices, and the sensory stimuli produced by those devices. There are three major categories of display fidelity, based on the type of sensory stimuli being produced (LaViola et al. 2017): visual fidelity, auditory fidelity, and tactile fidelity.

Visual Fidelity

Visual fidelity is essentially the degree with which real-world visual stimuli are reproduced by an interactive system. For example, a VR head-mounted display (HMD), which provides an immersive stereoscopic view of the virtual environment, affords much greater visual fidelity than a standard-definition, non-3D computer monitor.

Several rendering factors affect visual fidelity. *Culling* parameters determine which objects will be rendered. *Shaders* define how the material properties of objects will be rendered, especially in reaction to the simulation's lights. *Post-processing* effects, such a motion blur, can then be applied to the rendered image. Finally, the computational requirements of these factors ultimately determine the *frame rate* (i.e., how often images are rendered to the graphics buffer).

Several qualities of visual displays also affect visual fidelity (LaViola et al. 2017). A display's *field of view (FOV)* defines the maximum number of degrees of visual angle that can be seen instantaneously. On the other hand, a display's *field of regard (FOR)* defines the total number of degrees of visual angle that surround the user and are accessible. For example, many consumer HMDs provide approximately a 90-degree FOV but a 360-degree FOR. *Stereoscopy* (i.e., the display of slightly different images to each eye) is another common feature of consumer HMDs. *Spatial resolution*, the ratio of display pixels to physical space, often expressed as dots per inch (dpi), is another quality that affects visual fidelity. For example, a handheld 4 K display has much greater spatial resolution than a large 4 K television. Finally, spatial resolution can also affect *refresh rate* (i.e., how often images are displayed from the graphics buffer).

Auditory Fidelity

Auditory fidelity is essentially the degree with which real-world auditory stimuli are reproduced by an interactive system. For example, 3D localized sounds rendered to a set of headphones afford greater auditory fidelity than 2D ambient sounds rendered to a set of speakers, which are prone to cross talk among channels.

Like visual fidelity, auditory fidelity depends on several rendering factors (Taylor et al. 2009). *Sound synthesis* (i.e., the generation of audio signals based on interactions between virtual objects) relies on either physics-based simulations or prerecorded audio samples. *Sound propagation* then determines how the synthesized sounds propagate through the virtual space to the listener's ears based on attenuation, reflections, refractions, and diffractions. These propagated audio signals are then *panned* independently to one or more channels and then *mixed* to produce an auditory image (Gregory 2017). Finally, this auditory image is produced through *acoustic vibrations* with either headphone, which support two channels, or external speakers, which can support multiple channels (LaViola et al. 2017).

Tactile Fidelity

Tactile fidelity is the degree with which real-world sensations of touch are reproduced by an interactive system. The Longbow archery subgame from

Virtual Reality System Fidelity, Table 1 A brief overview of the components of system fidelity

System fidelity	Interaction fidelity	Biomechanical symmetry	Anthropometrics Kinematics Kinetics
		Input veracity	Accuracy Precision Latency
		Control symmetry	Transfer functions
	Scenario fidelity	Physical coherence	Colliders Mass Center of mass Gravity Velocity Drag Angular velocity Angular drag Constraints
		Behavioral coherence	Perceptual model Cognitive model Motor model
		Attribute coherence	Mesh representation Material
	Display fidelity	Visual fidelity	Culling Shaders Post-processing Frame rate FOV FOR Stereoscopy Spatial resolution Refresh rate
		Auditory fidelity	Sound synthesis Sound propagation Panning Mixing Acoustic vibrations
		Tactile fidelity	Frequency Amplitude Duration Asynchrony Tactile vibrations Spacing

The Lab, a VR game by Valve, is anecdotally regarded to provide high tactile display fidelity for pulling on the string of an archer's bow by many users.

Several rendering and device factors affect tactile fidelity. The *frequency* and *amplitude* of a tactile signal can have a significant effect on its perceived intensity (Seo and Choi 2010). When multiple tactile signals can be produced, the *durations* and *asynchronies* of the stimuli can create tactile perceptual illusions, such as phantom actuators and apparent tactile motion (Israr and Poupyrev 2011). These tactile signals are then commonly produced through *tactile vibrations* with either linear resonant actuators (LRAs) or eccentric rotating mass (ERM) motors (Tang et al. 2014). The *spacing* of these motors also affects the overall tactile fidelity (Tang et al. 2017).

Effects of Display Fidelity

Display fidelity has also been shown to have significant effects on user performance and experience. Increased visual fidelity has been shown to significantly improve performance in manipulation tasks (Ware and Franck 1996) and travel tasks (McMahan 2011). Visual fidelity also has a positive effect on presence, engagement, and perceived usability (McMahan et al. 2012). High auditory fidelity has been shown to both improve memory recall and increase presence (Dinh et al. 1999). Similarly, high tactile fidelity has been shown to afford the body ownership illusion (i.e., considering a virtual avatar body to be your own), while low tactile fidelity does not (Kokkinara and Slater 2014). In general, unlike interaction fidelity, increasing display fidelity improves user performance and the user experience.

Conclusion

System fidelity is well-structured, hierarchical concept that incorporates interaction fidelity, scenario fidelity, and display fidelity, as depicted by the user-system loop (see Fig. 1). In this entry, each subcomponent has been defined and further decomposed into contributing aspects and factors that influence system fidelity (see Table 1). Additionally, some of the effects of each subcomponent have been briefly discussed, demonstrating that system fidelity can have a significant impact on user performance and the user experience.

Cross-References

- ▶ Information Presentation Methods in Virtual Reality
- ▶ Natural Walking in Virtual Reality
- ▶ Perceptual Illusions and Distortions in Virtual Reality
- ▶ Virtual Hand Metaphor in Virtual Reality

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Virtual Reality Systems

▶ Immersive Virtual Reality Serious Games
▶ Locomotion in Virtual Reality Video Games

Virtual Reality Systems, Tools, and Frameworks

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Synonyms

Immersive environments; Virtual environments; Virtual reality components; Virtual reality engine; Virtual worlds

Definition

A virtual reality system is a software system that generates the illusion of immersion and presence within a virtual environment. A virtual reality framework is a customizable application that consists of design patterns and components, which assist virtual reality developers with its modularity, reusability, and extensibility. Virtual reality systems and frameworks may be developed using special purpose virtual reality development tools.

Introduction

Virtual Reality (VR) has been gaining a lot of attention in the past few years. Although the first VR Head-mounted Display (HMD) was designed in 1968 by Ivan Sutherland, the broad adoption of the VR technology is realized around 50 years later due to the emergence of affordable VR HMDs, and the maturity of computer graphics. Nowadays, VR simulates interactive virtual environments that immerse users to the extent that they become subjectively involved and experience the illusion of presence. VR research and industry is very active the past few years in the development of innovative methods for VR, VR systems, development tools and VR frameworks.

VR Systems

A VR system is a software system that aims to provide synthetic user experiences that stimulate user senses. Main objective of a VR system is to generate the illusion of immersion and presence within a virtual environment (VE) by providing artificial computer-generated stimuli to the user. In addition, immersed users should have the ability of interacting with the VE in a natural way.

A VE, a key element for every VR system, is a digital model that consists of spatially organized virtual objects. Its utilization assists the simulation and enhances the virtual user experience.

The basic architecture of a typical VR system involves several hardware and software components which cooperate to generate the artificial stimuli. Core of the system is the computational platform that is responsible of running an appropriate game engine, which maintains the VE, keeps track of its state, interprets, and executes user commands. User interaction is accomplished utilizing various input and output devices while the artificial stimuli are presented to the user utilizing one or more output devices.

VR systems are mainly distinguished from other software systems due to the complexity of accomplishing simultaneously system objectives some of which may be conflicting. Such systems are characterized by two defining properties, user immersion and real-time interaction, that help achieve human sensory stimulation. These properties impose a strict set of requirements onto VR systems which are directly deduced by properties of the human sensory system. The requirement of strict real-time performance is set to ensure an acceptable level of realism and presence. Additionally, such software systems need to model the appearance, the functionality, and the physical properties of virtual objects within the VE. As these systems aim to create an immersive illusion for the user, different styles and modalities of interaction techniques in accordance with specific tasks, utilizing input/output devices, should be taken into consideration.

The development of a VR system is a multidisciplinary task involving sensing and tracking technologies, stereoscopic displays, multi-modal interaction and processing, computer graphics and geometric modeling, dynamics and physics enabled simulations. As such, various types of displays, sensors, and computer systems are utilized. Stereoscopic displays aim to deliver the sensory stimulation to the user, sensors detect user actions, while computer systems process user actions and generate the output content. VEs are presented to the user through HMDs that involve sensory display systems, sound speakers, and force feedback devices.

Primary objective of a HMD is to present the VE to the user, hiding the physical scenery. This functionality enhances the full immersion of the user within the VE. HMDs have capabilities of displaying real-time stereoscopic imagery, acquiring head tracking, and providing haptic and force feedback to the user with several degrees of freedom. Also, many HMDs provide other input methods, such as speech recognition, and user data acquisition through data gloves, or data suits. Nowadays, untethered HMDs, having the benefit of being wireless and running on their own computational unit, using ARM processors, are independent of a personal computer (PC). The smartphone technology mVR (Wei et al. 2017) has enabled the production of mobile and low-cost HMDs which use smartphone cases with mounted lenses. Although, this technology seems a promising solution, it may not support

full user immersion since it lacks input control sensors for user interaction.

A data glove is a device that captures the user's hand gestures such as the position of the hand, the orientation of the hand, and the orientation of the finger joints. A pinch glove is a similar device with the data glove with no finger joints orientation measurement. Many other VR input device are also available such as mechanical trackers, electromagnetic trackers, acoustic trackers, optical trackers, inertial trackers, face trackers, haptic displays, cave automatic virtual environment (CAVE), etc.

Successful real-time rendering of complex VE require a powerful special-purpose software engine running on dedicated computational platforms. Nowadays, these technical considerations gradually become less important due technological advances in microprocessors, graphics processing units (GPU), display technologies, motion tracking technology, etc. As such, VE designers focus more on the quality of user experience.

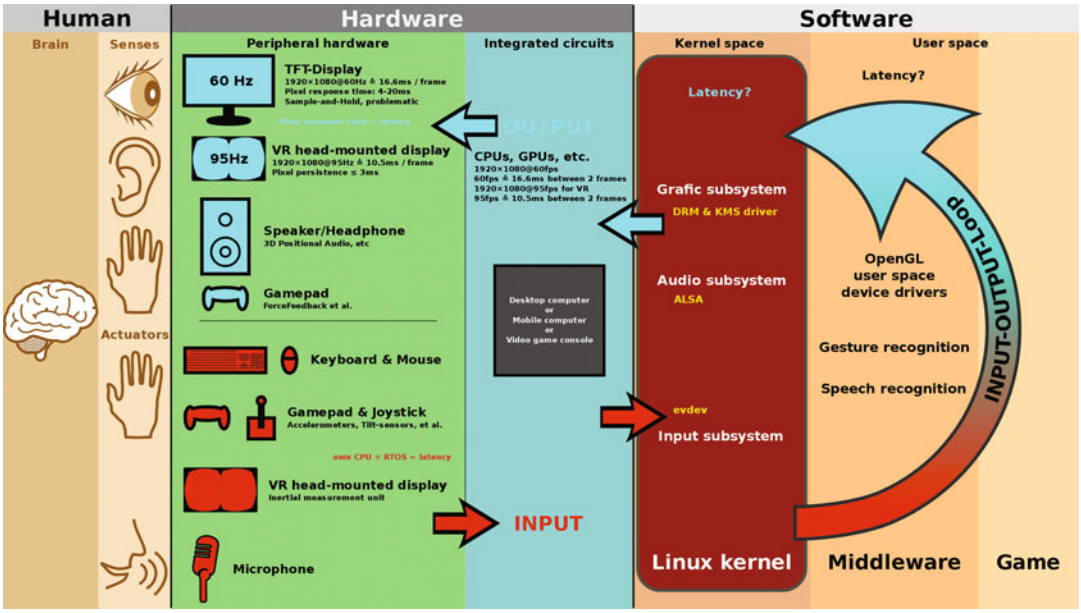
Components of a VR System

The generation of an amination requires the minimal frame rate to be at least 24 frames per second (FPS), while the optimal frame rate may be much higher, 60–100 FPS. This requirement makes the VE engine to be a very important part of the VR system. The VE engine consists of several important components, namely, Scene graph, Graphics Rendering engine (Papagiannakis et al. 2014), Audio engine, the Physics simulation engine, and the user interface (UI) system. The central component of each VR system is the Scene graph, an abstract representation of the VE represented by a data structure containing the properties of each virtual object, such as description, relative position, transformation, lighting, material, and texture. This component contains modules for the stereoscopic display. The Graphics rendering engine is responsible for generating the 2D image that is to be projected on the HMD, by transforming in real-time the 3D scene into a 2D photorealistic image. To accomplish the image generation, the rendering engine considers a mathematical lighting model, with the virtual object geometry and the light reflecting properties of its surface material (Gillies and Spanlang 2010; Jung et al. 2011). The Audio engine generates spatialized audio, simulating the changing properties of 3D sound as it travels from the virtual source to the listener in the VE. In many VR systems, the graphics rendering engine collaborates closely with the Physics simulation engine (Papagiannakis et al. 2018). Physics engines are software modules responsible for simulating the dynamic behavior of virtual objects considering physics laws about forces, masses of objects, friction coefficients, velocities, accelerations, elasticity coefficients, etc. Physics engines contain surface deformation and collision detection modules (Papagiannakis et al. 2018; Xiao et al. 2020). Finally, the UI system is responsible for the interpretation of the acquired, from the various input sensors, user interactions into meaningful gameplay events utilizing the defined game logic.

Figure 1 shows a pictorial view of the entire VR pipeline. The input subsystem receives sensed data from the various input devices which are further processed converted to user interaction commands by the speech or gesture recognition subsystems. Following, depending on the issued user command the OpenGL subsystem generates the new transformation of the virtual environment. Also, the Audio subsystem generates the sound to be played. Last stage of the VR pipeline is the transmission of the image and sound to the output devices.

Depending on the employed computational platform VR systems are categorized as PC-based, mobile, and Distributed VR Systems.

Many VE provide multi-user collaboration that may be supported by distributed VR system architectures. Such systems are mainly distinguished from other distributed software systems due to their strict requirements in terms of presenting a common interactive environment and its state to all users, as well as providing means for mutual communication and collaboration among the users. Furthermore, a fast and reliable data transfer method is also required as these systems produce large amounts of data. In a multi-user VR



Virtual Reality Systems, Tools, and Frameworks, Fig. 1 Important constraints for best immersion are high frame rate and low latency (https://en.wikipedia.org/wiki/Virtual_reality)

system, to maintain the consistency of the VE, all users must be constantly synchronized regarding the state of the VE. Among others, the VE State includes the positions and transformations of virtual objects, their visual appearance in terms of material, lighting, and texture. State synchronization maybe accomplished through various sync strategies: shared repository where the state of the VE is kept in a single location on a dedicated server, frequent state regeneration where each client/peer maintains its own copy of the VE and broadcasts the updated information to every other node in the network, dead reckoning where each client/peer in the network maintains its own copy of the VE, calculates the position of other clients according to their position, speed, and direction and periodically broadcasts basic states to other nodes.

Distributed VR systems (Wei et al. 2017) are mainly designed using similar network architectures as in other distributed software systems, Serverless pear-to-pear (P2P) and Client-Server architectures. In serverless architectures, VR systems are characterized by high availability and extensive bandwidth use. On the other hand, in Client-server architectures, a single dedicated server is responsible for maintaining and transferring the state of the VE to all clients. In this setup, the complexity of the network is simple, but the server is a rather critical point of the architecture. In a multi-server client-server system, the workload is divided across many servers, which raises the number of concurrent users. Also, the communication bottleneck is reduced compared to the single server setup, and there is no single critical point of failure. Such architecture is more complex and introduces much redundancy while synchronizing the state between the servers.

VR Development Tools

Game and VR engines are software tools for the development of interactive VR experiences aimed at generating immersive and photorealistic synthetic environments. VR engineers are required to program in a high-level programming language, have solid modeling knowledge, and graphic design skills. Most popular VR engines may be integrated with customizable VR software development kits (SDK) and application programming interfaces (API).

Unity is a powerful cross-platform game development environment and runtime engine. Unity allows game deployment on mobile platforms, consoles, handheld gaming platforms, desktop computers, TV boxes, and virtual reality systems. Unity's main advantage is the ease of development using an integrated editor environment. It also provides a powerful set of tools for analysis and optimization of the virtual environment for a specific platform. VR engineers may design and manipulate assets and game entities. Scripting may be implemented using JavaScript, C#, or Boo and a shader language for custom GPU shaders. There is also support for network multiplayer games. It provides a built-in physics engine that handles contact dynamics, as well as material simulation. Unity VR systems may be integrated with most common VR hardware.

The *Unreal Engine* provides an extensive set of features and tools. It is a powerful virtual environment development platform and prototyping tool. Scripting may be implemented in C++ and scripting technique called Blueprints Visual Scripting that enables VR engineers to collaborate using the same set of tools. Unreal engine is more complex and sophisticated tool than Unity, but it realizes better performance. It supports all main VR hardware.

CryEngine is another game development platform which offers a rich suit of tools for asset creation. Its powerful runtime engine features high quality real-time graphics targeting into a wide range of platforms. Scripting is implemented with C++. It may support three VR platforms: HTC Vive, Oculus Rift, and Open source virtual reality (OSVR).

WebVR is a recent VR development platform. It contains a JavaScript API that allows VR deployment in most modern browsers. *A-Frame* is an open-source Mozilla project allowing the design of VR experiences using HTML. *A-Frame* project may run on various HMDs, HTC Vive, Oculus Rift, Google Daydream, and Samsung Gear VR. *React 360* is a promising framework that use native react logic using only JavaScript and Node.js.

VR Frameworks

In software engineering, an object-oriented application framework (OOAF) is a customizable set of modules that consist of design patterns, which assist software engineers with modular, reusable, extensible components. VR development involves many intensive subtasks as programming, 3D graphics, animation, and audio engineering. Therefore, it is a complex task. Frameworks tend to reduce the architectural complexity of VR system through reusable system design and common class vocabulary. To this end, a VR framework's objective is to assist VR engineers in developing fast and efficient VR applications. The challenge of a VR framework is to provide abstraction classes of devices, projection system, specialized scene graph, VE interaction system, and support for distributed VR systems, ready for reuse. Therefore, the development process is simplified since generic functions and features are available for reuse at any kind of VR application (Ponder et al. 2003). VR frameworks are scalable and customizable to the developer needs (Papagiannakis et al. 2018). As such, the employment of a VR framework enables the VR engineer to focus on the design of the virtual environment rather than programming the core functionalities of a VR application.

SteamVR framework mainly provides an HMD controller, input mappings, and tracking system. A number of frameworks were developed on top of SteamVR enhance the interactions and object manipulations in the virtual world.

Other frameworks deal with other functionalities like 3D menus and character control systems (Gillies and Spanlang 2010; Jung et al. 2011; Takala 2014; Dam et al. 2015). Many of these frameworks aim to exploit virtual reality as a medical training tool for medical operations (Papagiannakis et al. 2018; Pfeiffer et al. 2018), manufacturing operations (Whitney et al. 2018) or for product marketing presentations (Alcañiz et al. 2019). Although consumer VR systems are now affordable, content creation still requires a significant development effort. Also, some device-agnostic VR frameworks have already been developed that various HMDs without requiring

any special adaptations (Papagiannakis et al. 2018).

Cross-References

- ▶ EEG as an Input for Virtual Reality
- ▶ Foundations of Interaction in the Virtual Reality Medium
- ▶ Immersive Technologies for Medical Education
- ▶ Immersive Virtual Reality Serious Games
- ▶ Immersive Visualizations Using Augmented Reality and Virtual Reality
- ▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
- ▶ Online Players: Engagement, Immersion, and Absorption Across Secondary Worlds
- ▶ Presence and Immersion in Virtual Reality
- ▶ Storytelling in Virtual Reality
- ▶ Virtual Reality Retailing

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Virtual Reality Therapy

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Synonyms

Mental disorder; Simulation for therapy

Definitions

Virtual Reality Therapy (VRT) refers to the use of Virtual Reality (VR) technologies to conduct therapy by exposing the patients to stimuli in controllable and often interactive virtual environments. These interactive VRT interventions are designed to replicate artificial environments in which the user can experience stimuli tailored to treat a specific ailment. The virtual environments are presented to the user via head-mounted displays, cave automatic virtual environments, or desktop-

screens, while the user input is recorded by sensors, cameras, or traditional keyboard, mouse, and joysticks.

Introduction

By substituting real-world sensory information with digitally generated ones, VRT offers interactive, controllable simulations in which therapeutic interventions can be implemented. One of the first known published studies on VRT assessed the effectiveness of virtual environments in the treatment of agoraphopia: the fear of places that might appear difficult to escape from (North and North 1994). Since this pioneering study, a vast body of research on virtual technologies to treat mental conditions has been conducted. These studies investigate the effectiveness of VRT to treat conditions such as autism (Didehbani et al. 2016), anxiety disorders (Botella et al. 2017), poststroke patients (Lohse et al. 2014), phychoses (Rus-Calafell et al. 2017), and substance use disorders (Hone-Blanchet et al. 2014). The increasing capabilities of VR hardware, combined with its decreasing costs, are making VRT more easily accessible to therapist and mental health professionals. The main opportunity provided by VR technology is the ability to create naturalistic settings in which procedures for treatment of mental disabilities can be implemented. Traditional neuropsychological methods have been criticized due to their limited ecological validity. The critics have questioned the conventional interventions' ability to predict or improve real-world behavior via interventions performed in controlled environments such as the therapist's office (Chaytor et al. 2006). On the contrary, the ecological validity is described as one of the main strengths of VRT due to its ability to offer virtual simulations of reality that require real-world behavior as input from its users (Rizzo and Kim 2005). However, extensive usability testing is required to design natural user interfaces that are easy to use for individuals diagnosed with mental disabilities. The technological advancements in the area of 3D user-interface devices such as the Oculus Rift touch controllers have the potential to provide a user-friendly interaction scheme for future VRT interventions. Another main strength of VRT is the ability to deliver hierarchical treatments across different difficulty levels while supporting repetition in safe and controllable virtual environments. These environments can provide their users with real-time performance feed-back, which is essential to rehabilitation and learning interventions (Evans 2003). Thus, VRT interventions can be tailored to suit different needs and requirements of individuals diagnosed with a mental disorder, while allowing cheap duplication and distribution of the treatments to others with similar needs. Additionally, gamification capabilities of VRT interventions, as well as the possibilities for the sensation of "being there" (Sanchez-Vives and Slater 2005), can further increase the users' motivation for partaking in VRT treatments. In the following sections, a summary of VRT for some of the most studied areas is presented.

VRT for Exposure Therapy

According to the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association 2013), an anxiety disorder is a mental disorder, characterized by a significant level of anxiety and fear. Treating phobias has been one of the most efficient appliances of VRT (Freeman et al. 2017). VR affords the opportunity to expose the patients to virtual environments that seek to provoke anxiety and then remove that anxiety through repetition in a safe and controllable environment. VR exposure therapy is not a new method to treat phobias, but merely a technology that can assist the therapist to conduct traditional exposure therapy in controlled and ecological environments. More specifically, VRT provides access to situations that are otherwise inaccessible or uncontrollable such as fear of heights or flying in Acrophobia patients (Emmelkamp et al. 2002). A recent systematic review of VR exposure therapy for phobias within the past 5 years (Botella et al. 2017) showed that conditions applying VR to perform exposure therapy are significantly more effective than nonactive control conditions. However, the comparison

between VR-based exposure therapy and active-conditions such as in vivo exposure therapy often illustrated no significant difference. A study conducted by Bouchard et al. was alone in finding results favoring VR exposure therapy when treating individuals diagnosed with social anxiety disorder (Bouchard et al. 2017). In their study, a group of 59 patients diagnosed with Social Anxiety Disorder were randomly assigned to three groups: 17 received VRT, 22 received in vivo exposure therapy, while 20 were placed on a waiting list. The individuals put in the in vivo group received standardized treatments for 14 weekly 60 min sessions. All of the therapists involved in the study had at least one year of practical experience with in vivo exposure therapy. The exposure consisted of role-playing and exposure to social scenarios either inside or outside the therapists' office. These included situations such as asking strangers on a date, wearing two socks of a different color in public, giving an awkward speech to an audience consisting of the therapists' colleagues, etc. The VRT exposure treatment consisted of eight different scenarios such as meeting unfriendly neighbors, having a job interview, or introducing oneself to strangers. Posttreatment effects were measured using Liebowitz Social Anxiety Scale. Improvements were measured on both the VRT and the in vivo group. However, results indicated that exposure in VR was more effective than in vivo. A follow-up study showed that the improvements were maintained after 6 months.

VRT for Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) describes a wide range of pervasive, lifelong neurodevelopmental disorders characterized by severe impairment in social and communicational skills of individuals diagnosed with it (American Psychiatric Association 2013). Social skills training (SST) interventions such as role-playing, social stories (Delano and Snell 2006), and video modeling (Bellini and Akullian 2007) are currently being used to teach people diagnosed with ASD ways to appropriately interact with others. VRT as an SST intervention enables rehearsal of social skills in control environments, allowing the individual to work at his or her own pace. This is particularly useful for the ASD population given their discomfort with unpredictable situations and interaction with other people. Given the VR technology's ability to provide a continuous stream of artificial stimuli that leads to the perception of ecological and nonsynthetic environments, it is possible to assess and practice social scenarios and encounters (Adjorlu et al. 2017; Mitchell et al. 2007). Additionally, multimodal interfaces can provide better learning conditions via cognitive integration and limited cognitive load compared to single modality learning interfaces (Moreno and Mayer 1999). It is argued that daily living skills training that involves spatial and visual cues, which is the case with VRT social skills application, is more preserved in children and adolescents diagnosed with ASD. Technology-based learning interventions have generally been suggested to be useful learning tools for young people with ASD (National Research Council 2001). The primary application of VRT for the autistic population has been to create social scenarios in virtual environments that provide relevant contexts for learning. Didehbani et al. (2016) measured the effects of social skills training in virtual environments on a total of 30 children between the ages of 7 and 16 diagnosed with ASD. These virtual environments consisted of a variety of locations including a school classroom, a canteen, a playground, and a park. Each participant completed ten VRT sessions with a peer and two trained clinicians experienced in working with ASD. The clinicians and the participants all logged into the same virtual environment. The participants logged in with avatars designed to look like themselves. One of the clinicians logged in as a social coach, while the other played different roles in the social scenarios. The VRT intervention required interaction via keyboard, mouse, and microphone while pro-viding feedback via 24-in computer screens and headphones. The scenarios were designed to target social learning objectives in every-day real-world situations often faced by children. These include dealing with a bully, bonding with a

friend, meeting new people, or handling social dilemmas. During each of the 10 VRT sessions, three different scenarios were used, each consisting of ten minutes of interaction within the VR environment followed by five minutes of therapy with the clinician. Pre- and post-treatment measurements were performed using a Developmental NEuroPSY-chological Assessment (NEPSY) toolkit, as well as Social Attribution Task. The results revealed improvements in the participants' measured social skills, shedding light on the potential of VRT as a treatment tool for children diagnosed with ASD.

VRT for Poststroke Patients

A stroke occurs when the blood flow to an area of the brain is cut off, depriving the brain cells of oxygen and thereby killing them (Sardegna 2002). The death of brain cells results in the loss of the abilities controlled by that area of the brain. Around two-thirds of stroke survivors will therefore have some disabilities. These deficits are often motoric functions, requiring a considerable amount of practice to induce functional recovery (Kwakkel 2006). However, research indicates that poststroke patients perform limited repetitions of the required movements in the traditional therapy sessions (Lang et al. 2009). Furthermore, some motivational, logistical, and individual barriers limit the effectiveness of conventional therapy for poststroke treatment (Langhorne et al. 2009). VRT is one of the proposed methods to intrinsically motivate the poststroke patients in performing the required therapy sessions while removing the physically demanding traveling required for face-to-face interaction with the therapist (Lohse et al. 2014). The user interacts with VRT environments designed for poststroke rehabilitation through a variety of mechanisms. These can include sensors or cameras designed to measure the users' physical movement, while appropriate feedback is delivered via head-mounted-displays or screens. A review on VRT intervention for poststroke rehabilitation (Lohse et al. 2014) showed that in general, VRT was a slightly more efficient approach for upper-limb training compared to conventional interventions when measured using the Fugl Meyer Upper Extremity Scale. Subramanian et al. (2013) compared upper-limb in virtual environments to conventional physical environments on 32 participants sustaining a stroke 6–60 months before the study. The baseline of participants' stroke severity was set using the Fugl Meyer Upper Extremity Scale followed by a randomized placement of the participants in the VRT and the conventional therapy group. The task of both the VRT and conventional therapy group was to repetitively point towards six targets place just beyond arm's length without physically touching the target. Each therapy session averaged 45 min in both environments, repeated for 12 days spaced over 4 weeks. The poststudy assessment using the Fugl Meyer Upper Extremity Scale showed improvement in both groups, while the VRT group slightly outperformed the conventional therapy group. According to the authors, the slight improvement of the VRT group might be due to the extrinsic motivation induced by the implemented scoring system as well as the interactivity and novelty of the system.

VRT for Psychosis

Psychosis describes a range of psychotic disorders that involve disturbances in thought, perception, cognition, and social functioning of individuals diagnosed with it (Al-Diwani et al. 2017). The most common form of psychosis is Schizophrenia, a mental disorder that results in failing to understand what is real, often resulting in hallucinations and delusions (American Psychiatric Association 2013). The conventional treatment has been medication and, to a lesser extent, cognitive remediation therapy. Traditional neurocognitive assessment of individuals diagnosed with psychosis mental abilities in a laboratory setting has been criticized for having limited generalizability to real-world contexts (Chaytor

et al. 2006). Studies on VRT interventions for assessing psychotic symptoms, treating psychotic disorders, or enhancing the understanding of them have proven effective (Rus-Calafell et al. 2017). Sorkin et al. (2008) used a VR environment to measure the distortion in reality perception in schizophrenia patients. A total of 43 Schizophrenia patients and 29 healthy controls navigated through a predetermined path in VR environments consisting of a residential neighborhood, a shopping center, and a street market. The VR environments were designed to resemble the real world as close as possible, except some predetermined incoherences. These incoherencies included colors such as a pink road crossing and clouds, sound such as a guitar emitting trumpet sounds, or locations such as a live giraffe located in an interior store. Results indicated that 88% participants diagnosed with Schizophrenia failed to detect the incoherencies, while all of the participants in the control group rightly detected them.

Cognitive Remediation Therapy (CRT) is an intervention designed to improve neurocognitive abilities such as attention, memory, and executive functioning, often performed on individuals diagnosed with psychosis (Wykes and Spaulding 2011). Chan et al. (2010) conducted a study to investigate the effects of VRT as a cognitive remediation therapy tool for older adults with chronic schizophrenia at care-center for people with mental illnesses. A group of 12 participants received VRT-based CRT in 10 sessions. The system consists of a camera that via computer-vision algorithms tracks the users' body movements, while feedback is provided to the user via a big screen. Two VR activities with the purpose of training the participants' attention, memory, and executive functioning were chosen. These consisted of an activity that involved the participant attempting to block the path of balls flying towards him using his body movement and another activity within which the participants avoided getting attacked by sharks in their way by leaning from side to side. The participants' posttreatment performance was measured using the neurobehavioral cognitive status examination (Cognistat) and compared to a control group that received the standard treatment offered at the care center. The overall cognitive functioning performance of participants in the experimental group was significantly better than the control group, showing the potentials for VRT treatment for individuals diagnosed with Psychosis.

VRT for Substance Use Disorders

According to the fifth version of the diagnostic and statistical manual on mental health disorders (American Psychiatric Association 2013), Substance Use Disorder (SUD) refers to the overuse, dependency, and craving for substances that lead to clinically significant impairment or distress. These include substances such as nicotine, alcohol, crack cocaine, and methamphetamine. Treatment of SUD via pharmacotherapies exhibits relatively poor success rates, showcasing the need for more effective interventions (Hone-Blanchet et al. 2014). Studies show that Cue-Exposure Therapy (CET) in combination with pharmacotherapy is necessary for treating SUDs (Perry et al. 2011). Individuals diagnosed with SUD have often established an association between visual cues (objects such as syringes or environments such as bars) to their psychological craving response. CET designed for individuals diagnosed with SUD aims at exposing the patient to the visual cues associated with their cravings. Being exposed to these visual cues without the presence of the actual craving inducing substance will decrease the negative reactivity to the visual cue.

Kuntze et al. (2001) conducted the first study to investigate the effects of VR as a CET tool for individuals diagnosed with SUD. A virtual environment presents the user with a bar scene, with visual cues such as syringes. Via an in-between study, three different groups, each consisting of five individuals with opioid dependence, went through three different treatments: CET via VR, CET via pictures, and CET via books. A variety of craving scales were measured at baseline and

during and after the interventions. All five individuals in the CET via VR group reported unpleasant feeling and urges to use Heroin. Applying VR IN CET treatments exceeds traditional CET designs, which mainly uses substance-related cues detached from its in vivo context (Drummond and Glautier 1994). A range of studies has since confirmed the positive effect of VR to induce craving for substances such as cigarettes and alcohol, indicating VR as an applicable tool to perform CET (Hone-Blanchet et al. 2014). However, there is a lack of studies investigating the long-term effects of VR-based CET.

Conclusion

A majority of studies on VRT, concerning the treatment of anxiety disorders, have found it a promising method of treatment in psychiatry albeit its full potential has not yet been explored. Despite an exponential increase of publications on VRT interventions, the utilization of VR to treat other common mental disorders such as ASD, psychosis, and depression is still in its preliminary stage, yet to be fully implemented in the clinical contexts. In general, research on VRT is often obscure, distinctly piecemeal, and seldom lived up to the standard of what is expected in clinical research today. This could be due to the novelty of the technology as well as restrictive access to individuals diagnosed with specific neuronal disabilities; thus, VRT is an area of research ripe for future work. The director of the Medical Virtual Reality at the University of Southern California, Albert "Skip" Rizzo, argues that VRT has the potential of being a revolutionary tool for psychologist, by merging the control of laboratory settings with the ecological validity of real-world environments (Parsons 2016).

Cross-References

► Mindfulness, Virtual Reality, and Video Games

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Virtual Reality Training for Daily Scrum Meetings

► Virtual Reality-Based Daily Scrum Meetings

Virtual Reality: A Model for Understanding Immersive Computing

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Synonyms

Engagement; Interaction; Mental immersion; Physical immersion; Quality of experience; Spatial perception

Definition

Virtual reality model allows the user to subjectively be involved and become immersed within a computer-generated environment. As the physical world is hidden, the user realizes the virtual environment as real while the acquired sense of presence enhances the feeling of immersion.

Introduction

Immersive computing has been gaining a lot of attention the last decade, due to advancements and innovations in hardware and software. The first reference to the term of immersive simulation was done in 1968 by Ivan Sutherland when he designed the first Head-Mounted Display (HMD) (Sutherland 1965). Nowadays, immersive computing enables seamless, and fluid user interaction with technology that gradually becomes smarter as it leverages advancements in deep learning. Emerging applications, such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), enable a fundamental change in the way users interact with software systems.

Immersive Computing

Immersive computing is a new term used to describe applications that immerse the user by blurring the boundary between the digital and the physical worlds, providing an immersive experience. The general concept of immersion (Ponder et al. 2003; Jennett et al. 2008) is mostly used in games and VEs as the involvement of the user in the game environment causing lack of sensing the physical world, as well as providing the sense of presence in the virtual environment. Immersion in virtual reality, is an artificially generated perception of being physically present in a nonphysical environment (Slater 2014). The perception is generated by surrounding the VR user with images, sounds or other stimuli. A VR system places the user inside virtual 3D environment through a special computer graphics system. The user uses a HMD that tracks head movements and update accordingly the displayed images. The graphics system computes perspective-projected images derived from the 3D scene individually to each eye. The 3D scene is a mathematical model that describes the spatial location of the virtual objects, and animations of virtual objects within the scene. Users may interact with the virtual environment using data gloves, or handheld control devices. Main objective of VR is to substitute the physical world perceptions with the artificially generated virtual world. When sensory perceptions are effectively replaced, the human brain infers its perceptual model – its consciousness – from sensory virtual data stream.

Emerging immersive computing applications are changing the way humans interact with mobile smart devices. This technology is realized through four immersive technologies: 360° video streaming, VR, AR, and MR. 360° videos, recorded utilizing omni-directional cameras, allow users - viewers to control viewing orientation during playback. VR presents a simulation of a photo-realistic virtual environment experience, hiding the physical world, and giving users the sense of presence within the virtual environment. AR does not hide the physical world but augments it by overlaying virtual objects on top of the physical objects. MR mixes physical and virtual worlds and allows user interaction between physical and virtual objects in real time.

The term immersion is referred to the sensation of being involved within an environment. It may be categorized in two broad types: mental immersion and physical (or sensory) immersion. Mental immersion refers to an emotional state of the user being involved and deeply engaged in the experience. Immediate result is the suspension of disbelief which is the main objective of media creators. On the other hand, physical immersion is a specification requirement of VR systems, that replaces or augments the stimuli to the participant's senses. Not all human senses are being immersed though. Mental immersion is usually referred to as the sense of presence in a virtual environment (Lackey et al. 2016). VR provides the user the illusion of presence within virtual worlds (Slater and Sanchez-Vives 2016).

VR technology is classified in two categories: immersive and non-immersive (Yoo et al. 2017; Gaggioli et al. 2009). In general, VR technology is considered to be immersive in the case that it can replace the user's perception of the physical world with an artificially generated sensory stream.

Non-immersive VR provides users a computer-generated environment without hiding

the physical world. The user keeps control over the physical surroundings: visuals, auditory, and haptics. As such the user is not being immersed in the virtual world. Such VR systems utilize computers or video game consoles, displays, and input devices.

Fully-immersive virtual reality enables users to experience virtual environments, hiding the physical world. Users perceive only virtual surroundings: visuals, auditory, and haptics. The main objective of this VR category is to enable users perceive the synthetic world as the real one (Krokos et al. 2019). As such, users wearing a HMD are completely isolated from the physical surrounding. Additionally, the use of wireless controllers enables users to explore the 3D virtual environments and interact with virtual content. Fully immersive VR technologies have the potential to provide the user with the sense of full engagement within a virtual environment.

This technology utilizes HMDs in combination with other sensory devices to generate realistic stereoscopic images, animation, spatial 3D auditory, and haptics, to simulate the user's presence in a virtual environment. VR positions the participant's body within the virtual environment to affect virtual interaction events. HMDs are the most common immersive VR technology since they occlude the physical world and replaces it with virtually generated images. The embedded sensors in the HMD provide position and orientation data to the computational unit to dynamically adapt the user viewing angle – position.

Cave automatic virtual environment (CAVE) is an advanced and expensive immersive VR technology (Cruz-Neira et al. 1992). CAVE may be located in a cube-like space surrounding the user in which all six cube-faces (walls) serve as display stereoscopic screens. CAVE environments are restricted to be installed in a dedicated space dedicated that does not allow easy mobility. As such, CAVEs are relatively difficult to be broadly spread for education and training purposes. CAVE technology is particularly used in Cultural Heritage education (Ott and Pozzi 2008) within special theaters or museums.

Utilization of VR Toward Full Immersion

Full immersion is closely related and supported by the term of quality of experience (QoE) which is defined in (Brunnström et al. 2013) as the degree of delight or annoyance of an application or service user. In the case of a multimedia immersive experience, QoE is complex and multidimensional and encompasses several influencing system factors (Ebrahimi 2009), namely, content, network, media, and device-related influencing factors. Content factors include video spatial and temporal resolution, and graphical design elements. Media-related factors refer to encoding, resolution, sampling rate, media synchronization, etc. Network-related factors describe the transmission system (e.g., in terms of latency, delay, loss, throughput), while device-related factors specify the capabilities and characteristics of the systems/devices located at the end points of the communication path.

Based on a comparison study (Broeck et al. 2017), VR HMDs provide the most immersive experience against smartphones and tablets at the cost of high cognitive burden. Furthermore, a user's motion sickness is possible due to visual and auditory quality, interactive and ergonomic experiences, that affect the physical comfort of users. The HMD's ergonomics, weight, shape, temperature, is an essential pillar of a true VR immersive experience. The weight of the HMD should be as low as possible since it is a critical factor for head balance and body posture. Also, the temperature inside the HMD is also a key factor for a true immersion.

Tethered VR headsets (e.g., HTC Vive and Oculus Rift) are connected via cables to VR-ready personal computers (PC) or game consoles. Although these devices realize improved QoE, their users experience limited mobility. MoVR technology (Abari et al. 2017) using mmWave communication instead of HDMI cables provides a solution to mobility constraints but the required data rate is very high, 5–7 Gb/s. The emergence of untethered/standalone HMDs (e.g., Samsung Gear VR, Google Daydream) provide an alternative solution for the mobility issue. An untethered HMD user does not experience

mobility constraint as these devices have the ability to render stereoscopic images using local computational resources (ARM processor). Hence, the approach of combining untethered HMDs with MoVR requires the decomposition of the VR pipeline (sensing, rendering, physics, streaming, displaying) to move part of it on the untethered HMD. Also, an alternative approach moves the entire VR pipeline on the untethered HMD making it PC-independent. It is obvious that both setups, especially the second, experience higher temperatures inside the HMD and fast battery drain.

Physics and rendering processes are the key performance bottlenecks in VR systems. In a distributed VR system, part of the decomposed VR pipeline, computation-intensive tasks (physics, rendering, streaming), is offloaded on a content network server and the untethered HMD displays the streamed images and senses the user interactions. Moreover, to reduce bandwidth consumption the content server encodes the images before transmission, while the headset decodes them before projection. As such, the untethered HMD runs non-intensive tasks, avoiding high processor temperatures and battery drain. Also, as VR applications require better visual quality (e.g., 4K or 8K resolution), parallel rendering and streaming methods (Liu et al. 2018) have been proposed to reduce the end-to-end latency. Also, image caching techniques (Sukhmani et al. 2018) aspire to improve the overall QoE. This approach produces encouraging results in local high-speed networks maintaining QoE. On the contrary, it is rather not feasible to realize mobile immersive applications full potential when relying in 4G networking infrastructure, since the amount of streaming data is voluminous, and the requirement for low latency and high bandwidth is strict. Hence, 5G and edge computing will play a substantial role in making immersive computing a reality.

Cross-References

- ▶ EEG as an Input for Virtual Reality
- ▶ Foundations of Interaction in the Virtual Reality Medium
- ▶ Immersive Technologies for Medical Education
- ▶ Immersive Virtual Reality Serious Games
- ▶ Immersive Visualizations Using Augmented Reality and Virtual Reality
- ▶ Mixed Reality, Gamified Presence, and Storytelling for Virtual Museums
- ▶ Online Players: Engagement, Immersion, and Absorption Across Secondary Worlds
- ▶ Presence and Immersion in Virtual Reality
- ▶ Storytelling in Virtual Reality
- ▶ Virtual Reality Retailing

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Virtual Reality-Based Daily Scrum Meetings

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Synonyms

Virtual reality training for daily scrum meetings

Definitions

A daily scrum meeting is a useful, short, and informal communication activity for agile software development teams typically conducted at the same location and time, most likely before lunch. This meeting allows regular exchange of information among software team members starting with reporting the status yesterday activities to today's tasks and ultimately obstacles that they did encounter.

Virtual reality is a technology medium that allows an interface to individuals to interact with sensory rich computer-generated world, which might also include virtual and real individuals where participants could gain virtual experiences on real matters. Social interactions with virtual personas are considered more engaging and fun especially for training in software engineering concepts.

Introduction

Software development is a social endeavor where quality of social interactions among practitioners directly affects the quality and complexity of software development (Yilmaz and O'Connor 2011b). In particular, software development encourages more diverse teams of individuals and highlights the importance of practitioners' soft skills (Yilmaz 2013). These skills usually developed by the experience of practitioners while working on several different teams and interacting software practitioners with various personality traits (Yilmaz and O'Connor 2012). However, it is technically not that easy to encounter these situations if an individual has been working with a single team of professionals for a long period of time.

In this entry, an industrial case study on a virtual reality training environment for human-virtual persona interaction been discussed to reveal ways to train software professionals for daily scrum meetings with 3D virtual characters which have the ability to mimic verbal and

nonverbal behaviors and therefore convey distinctive personality characteristics.

Overview

In the last decade, agile development has changed the controversial development approaches by investigating practical ways for continuous requirements gathering and feedback with self-organized and self-directed teams and ultimately seeking mechanisms for fostering sustainable software development. These socio-economic mechanisms promote a sequence of refinement to achieve desired outcomes (Yilmaz et al. 2010). However, agile development activities require more social interaction among practitioners, and therefore, social aspects of software development emerged as an important asset for improving the software development process (Yilmaz and O'Connor 2011a).

Daily Scrum Meetings

Scrum is a simple and flexible software development framework and ultimately an enabler based on teamwork with an iterative progress (i.e., a sprint) to deal with volatile requirements (Schwaber 2004). The process essentially starts with a planning meeting, which continues with daily scrum sessions and it ends with a retrospective meeting. These meetings enable software teams to quickly identify and solve the issues as they arise. In particular, daily scrum meetings, which hold every day of a sprint, provide continuous feedback on project status and an opportunity to fix the problems as they arise. In addition, they are helpful for measuring individual productivity on daily basis. To sum up, daily scrum meetings guide software teams for performance visibility, project control and predictability, and ultimately mitigating several risks they might have faced (Schwaber and Beedle 2002). In addition, these meetings are not only for exchanging information but also raising consciousness among software team members who should make continuous planning through a sprint.

A daily scrum meeting requires a well-functioning social interaction pattern; otherwise, it may have unsuccessful results. In addition, it helps to reveal communication problems in software development teams. Although it is not a deep problem-solving meeting, such a face-to-face gathering among the team members requires effective communication and social interaction skills (Schiel 2011). Daily scrum meetings are more likely to be successful when team members known each other's personality characteristics. Consequently, an individual might likely to predict his or her teammate's reaction when a conflict arises. A software team member should share the understanding of team goals, coordinate their work efforts, share their problems and suggestions for improvement, and lastly, they should have to produce a sense of relatedness (O'Connor and Yilmaz 2015).

However, many practitioners reported that they have worked with a limited amount of software professionals and do not know how to respond individuals when engaging a conflict with unknown personality characteristics. To bridge this gap and orient new scrum team members, we propose a virtual reality-based training environment, which is (i) beneficial for onboarding new personnel and (ii) helpful to train individuals who might like to experience a conflict with a virtual character that was designed to have a divergent personality characteristic.

Virtual Reality

Virtual reality (VR) is a technology of illusion (i.e., computer-generated world) encompasses computer vision, digital image processing techniques, and display tools, which enable participants to interact with a digitally simulated environment that have an ability to fool the human senses as an artificial reality (Burdea and Coiffet 2017). VR aims to convince an individual for being in another realm (i.e., hypothetical environment) by receiving and producing data using a computer system.

To design a fully functional training system, a critical feature for a VR system needs to be equipped with 3D interactive virtual characters which may have mimic a set of gestures based

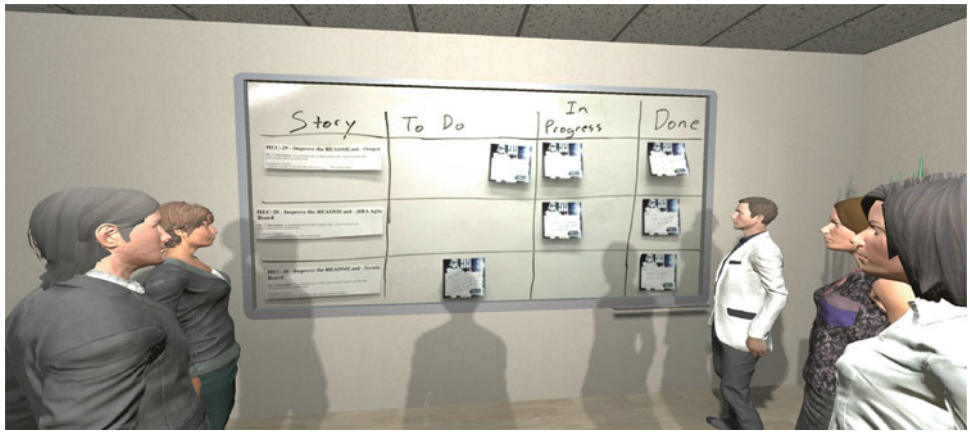
on their embedded personality characteristics. To improve the expressiveness of daily virtual stand-up meetings, we envision that Five Factor (a.k.a. Big Five or ocean) model of personality traits can be utilized for designing virtual personas to improve their social capabilities and make them useful in agile team training activities (Widiger 2017). Five-factor model considers the personality traits of a virtual character in five basic dimensions (Matthews et al. 2003): (i) openness to experience represents persons who are insightful with skills of imagination, (ii) extroversion represents talkative personas with energetic and assertive characteristics, (iii) agreeableness is a trait that shows cooperative behavior with compassion, (iv) conscientiousness is an organized responsible and consistent personality characteristic that shows a tendency to do any task well in a planned way, and finally, (v) neuroticism is a personality trait which is inclined to have long term negative emotions (e.g. anger, anxiety) while being tense and moody.

Personality in virtual characters are designed in terms of their verbal behaviors such as language usage skills (Mairesse and Walker 2010), nonverbal behaviors (McRorie et al. 2012) such as body language or gestures, and lastly facial expressions (Egges et al. 2004). Lui et al. (2016) suggested that extroversion trait in social virtual characters can be portrayed by higher speech velocity and gesture with wider arms than introvert personas. In particular, personality of a virtual agent can be characterized by a set of internally consistent verbal and nonverbal behaviors (Cerekovic et al. 2014). These agents can be formed to simulate different personalities (i.e., individuals with different verbal and non-verbal behaviors) of software professionals and beneficial for creating a variation of virtual daily scrum meetings.

Industrial Case Study: Applying VR to Daily Scrum Meetings

To enhance the virtual reality-based daily scrum meeting training environment, we initially designed five different personas with which participant can join collaboratively to a set of daily scrum meetings. The five personalities of the virtual software practitioners were based on the Ten-Item Personality Inventory (TIPI) scale (Gosling et al. 2003). Unlike human being, our synthetic humans were having more dominant characteristics. For example, virtual character A was designed as an extrovert who prefer to interact with others using verbal and nonverbal behaviors while Agent B was an argumentative virtual character who might avoid from small talk. The personality traits that utilized were as follows: extroverted, conventional, excited, argumentative, self-disciplined, emotionally unstable, and reserved.

Consequently, initial scenarios were created using recorded and transcribed from a set of real-world daily scrum meetings experienced by a small- to medium-sized software enterprise. The agents were hard-coded with predefined gestures and mimics to create a unique training experience to participants. The VR-based training environment aimed to introduce software practitioners seven well-known mistakes might happen in daily scrum meetings. First scenario was about a virtual character who started to take notes while scrum master initiated the meeting. Among active six virtual characters, two of them began to get annoyed from this situation which ultimately reflected to their nonverbal behavior. Here, participant should be able to recognize what was going on and advised to take notes about the issue. Second scenario was about micromanagement issue in a daily stand-up meeting, which was performed by a virtual personality. The virtual scrum master character started to solve a specific problem that was caused by another persona. While meeting was in progress, two other team members started to perform some gestures in response to that situation. In light of these remarks, the participant should be able to spot the problem and later asked to document the issue. The daily stand-up meeting aims to hold the team together by aligning team member's progress with a sprint goal. In the third scenario, virtual team members articulated some sense of disorientation. Initially, a virtual character started to play with their mobile phone during discussions. Participant could report impediments and



Virtual Reality-Based Daily Scrum Meetings, Fig. 1 A daily scrum meeting environment in virtual reality

ways of collaboration for fixing problems. Consequently, other virtual agents started to act in a noncollaborative manner while the other two were annoyed from this situation. Participant should be able to identify this problem and might suggest a solution for reorientation.

Figure 1 illustrates the virtual reality-based training environment where participant is situated in different roles depending on selected scenario. Participant can see all verbal and nonverbal behaviors of virtual characters, which are now in embedded code but planned to be arranged using a simple XML-based markup language.

Agile software development requires quick information exchange; however, the daily stand-up meeting sometimes considered as a planning activity where team leader presents a planned feature. The third training session includes a typical scenario initiated with a discussion regarding to a new feature. Accordingly, scrum master started such a conversation and a virtual character with relatively higher conscientiousness trait might likely to annoy from the situation and probably shows some gesture sequences. Participant should realize the problem and report it back with the user interface. Fifthly, this scenario was expanded to include a detailed technical discussion that should not be conducted during a daily stand-up meeting. All virtual characters partially might annoy from the discussion and highly likely to show their irritation by a set of nonverbal behaviors. An agile practitioner should be able to spot such an issue and report it to a team lead when necessary. In the sixth scenario, participant played the role of scrum master in which team members gathered up in their work location instead of holding the meeting near a scrum board. Consequently, virtual characters started talking to each other by showing some gestures. The goal of participant was to direct them to the right meeting place (i.e., in front of scrum board). Finally, a participant entered the scenario where conventional meeting context was affected by some extra discussions introduced by virtual characters. Participant should have to interact with virtual characters and observe unwanted behaviors. In addition, the main goal of the participant was to keep the values of information, concentration, and entertainment of the virtual daily scrum meeting in balance. In particular, individual should steer the conversations to tasks that they have done yesterday and the things they are working for today. Daily stand-up meetings are usually conducted before lunch; therefore, there would be a space to talk about today's tasks that are in progress. In this scenario, participant was called for an early meeting and further exposed to conversations related to constraints, risks, and obstacles. Participant should have to recognize the issue and report this when asked.

During the study, these seven scenarios were arranged for participants in the form of a set of

Virtual Reality-Based Daily Scrum Meetings, Table 1 The issues spotted by experienced software practitioners in virtual daily scrum meetings

Practitioner	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
P1	Found	–	–	Found	Found	–	Found
P2	Found	Found	Found	Found	–	Found	Found
P3	–	–	Found	–	–	–	Found
P4	Found	Found	–	Found	–	Found	Found
P5	Found	Found	–	Found	–	Found	–
P6	–	–	Found	Found	Found	Found	–

VR-based daily stand-up meetings. To investigate scenarios simulated in the VR environment, six software practitioners played all seven scenarios using a Oculus Rift Headset with a pair of Oculus Touch controllers. They were asked to spot a daily scrum meeting issue based on their hands-on experience. The scenario based issues that participants found were shown in Table 1.

Overall, these results indicate that all issues can be visible which were found either one of the participants. Participant one cannot find the daily scrum meeting issue for scenario 2, 3, and 6. Participant two scored six out of seven which is the highest score among all participants while participant three was the one with the lowest found value (i.e., two). Participant four found five issues, participant five and six could be able to report four issues. Not surprisingly, perhaps, participant three was a novice software engineering with less than 1 year of development experience, and participant 2 was a scrum master. Consequently, these preliminary results further highlight the potential benefits of a VR-based software development training.

Limitations

We have initially observed that VR has significantly helped to improve the learning experience for daily scrum meetings in an agile development team. Since the study was also limited to hardware (i.e., a single Oculus Rift was used), it was not possible to conduct concurrent assessments. In addition, it was observed that first time virtual reality users have some stress while experimenting virtual daily scrum meetings. A participant was a bit nervous to experience VR technology and concurrently responding to virtual characters with timely and appropriate responses. Therefore, an assistant observer was used for guidance. After passing the orientation phase, it seems all participants were somehow immersed. To create more realistic daily scrum meetings, a participant suggested that 3D environment should be more detailed with additional background office noises. In addition, another participant suggested that scrum board should be visualized with realistic data and all scenarios should belong to a single project, which would make it more easier to follow. However, these limitations may be improved in further studies.

Conclusion

This entry discussed a virtual reality environment to train software practitioners on daily scrum meetings. The goal was to create a virtual environment with virtual characters to enhance the learning experience of software professionals. Although research has been conducted to transform text-based learning to an interactive form, virtual reality offers an engaging and interactive experience especially by integrating virtual characters that act like human participants. The virtualization of information to use in training is an emerging field in virtual reality applications. Virtual characters with human like gestures and behaviors make a training system interactive and ultimately more engaging for participants. A virtual ecosystem may assist individuals to improve their learning efforts. Based on Scrum

rules that an agile team member should follow, seven different situations were simulated by virtual characters in a 3D virtual reality environment. Although the current study was based on a small sample of participants, the findings suggested that VR-based simulations could be helpful for training software practitioners. In other words, this study strengthens the idea that a scenario-based virtual reality training benefits software practitioners. There is a potential to gain virtual experience on various software development activities. Further research could also be conducted to determine the effectiveness of virtual characters in education and training in software engineering.

Although virtual reality is an emerging medium within a wide range of potential applications, it still has some reachability issues. However, there are massive amounts of investments in VR ecosystems by technology giants such as Google, Apple, HTC, etc. Therefore, this problem will be overcome with these massive investments. Finally, training in a virtual reality environment with virtual characters can be considered as an enjoyable experience particularly for technology enthusiast, like majority of the software practitioners.

Cross-References

- 3D Avatars in Virtual Reality Experience
- Gamification
- Gamification and Serious Games
- Storytelling in Virtual Reality
- Video Game Storytelling Fundamentals: Setting, Power Status, Tone, and Escalation
- Virtual Reality Applications in Education
- Immersive Virtual Reality Serious Games

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Virtual Retailing

▶ Virtual Reality Retailing

Virtual Shopping

▶ Virtual Reality Retailing

Virtual Systems

▶ Everyday Virtual Reality

Virtual Travel

▶ Natural Walking in Virtual Reality

Virtual Trial

▶ Virtual Reality Retailing

Virtual Volunteering

▶ Gamification in Crowdsourcing Applications

Virtual World, a Definition Incorporating Distributed Computing and Instances

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Synonyms

Massively multiplayer online role-playing game (MMORPG); Multiuser virtual environment (MUVE); Online world

"Virtual World" Definition

A simulated environment where MANY (one or more) agents can virtually interact with each other, act and react to things, phenomena and the environment; agents can be ZERO (exactly zero) or MANY human(s), each represented by MANY (a virtual self is not required to be unique herein) entities called a "virtual self" (an avatar), or MANY software agents; all action/reaction/interaction must happen in a real-time shared spatiotemporal nonpausable virtual environment; the environment may consist of many data spaces, but the collection of data spaces should constitute a shared data space, ONE (one and only one) persistent shard.

Introduction

There is no generally accepted definition for a virtual world, with Schroeder (2008) highlighting the need for a definition. There is controversy on the meaning of the term "virtual world" in various communities and research (Combs et al. 2004; Brennan 2009). Advances in systems architecture techniques such as host migration between instances, and distributed computing, bring in to question whether those architectures can actually support a virtual world. When a virtual world is not well defined and without a concrete definition, designing an architecture specifically for a virtual world is problematic, for example, tactics often used in existing publications are refraining from providing a reference to the virtual environment used, naming properties that constitute the virtual environment relative to their publication, or only referring to examples of existing implementations. Current definitions simply do not correlate to contemporary technologies, allowing for the classification of technologies such as the online productivity tool, Google (2007) Docs (GDocs); the video game, Leagues of Legends (LoL) (Riot Games 2009); the many shards of the virtual world, World of Warcraft (WoW) (Blizzard Entertainment 2004); or Facebook (2004). It does not buy us anything to refer to

everything as a virtual world, even though it might be possible.

To verify the definition, it is compared with related work. The properties found in Bell (2008) and Girvan (2013) provided a starting point for finding the properties contained herein. Results of this article include a detailed definition for a "virtual world," with detailed definitions of all underlying properties used. The resulting definition is tied to the accepted definition of a net-VE, by Singhal and Zyda (1999). And the concept of pseudo-persistence, by Söderlund (2009), has been used to categorize those technologies which only mimic persistence.

Definition Comparisons

Singhal and Zyda (1999, p. 3) state that a net-VE can be distinguished by five common features: a shared senses of space, a shared sense of presence, a shared sense of time, a way to communicate, and a way to share. A virtual world can be classified as a net-VE, where the multiuser restriction is relaxed to allow local play and simulations with no humans, and the environment is required to be persistent. A "shared sense of space" and a "shared sense of time" can be assumed to be equal to shared real-time spatiotemporal environment in definition herein. One disturbing sentence from Singhal and Zyda is that the place in a "shared sense of space" "may be real or fictional." It is assumed that this statement is mentioned to include the physical aspect of a video conference, but not meant to include pervasive systems (Nevelsteen 2015). If the latter is the case, there is not enough clarification provided to handle pervasiveness (see Mixed Reality (Milgram and Colquhoun 1999)), for example, if a virtual persona is projected into the physical world, is it still a net-VE? Singhal and Zyda's a "shared sense of time" implies real-time interaction, but in definition herein it is made explicit. A "shared sense of presence" implies support for avatars that can be "synthetic entities"; again this aspect is made explicit in definition herein through requiring software agents. The need for an avatar, mentioned in the "shared sense of presence," arises out of the fact that a net-VE is defined as a multiuser environment. It is not clear if the avatar requirement has a uniqueness constraint. In definition herein, a "way to communicate" and a "way to share" are considered part of action and interaction, with the different types in-game communication left as a distinguishing characteristic of different virtual worlds. Using both definitions, GDocs classifies as a net-VE, but not as a virtual world.

R. A. Bartle offered an updated definition in 2010 with respect to his previous publication (Bartle 2003), including the persistence criterion, stating a virtual world to be "an automated, shared, persistent environment with and through which people can interact in real time by means of a virtual self." The automated property specifies a set of rules by which players can change the world, but does not mention how the world can develop internally (previously a part of the persistence property). The definition refers to a shared environment, where "more than one player can be in the exact same virtual world at once," but usage of the term "virtual world" in the description leads to a recursion; it can be assumed to mean a shared spatiotemporal environment, but if the description is to serve as a definition this is problematic. The definition mentions interaction within the virtual world for people, but does not mention virtual interaction in the world, for example, software agents. R. A. Bartle (2010) altered the persistence criterion to state: "if you stop playing [and] then come back later, the virtual world will have continued to exist in your absence." The statement guarantees world persistence and can be assumed to include the nonpausable criterion, by Bell and Robbins-Bell, but fails to account for the difference between persistence in a single-player video game and a virtual world. Also, pseudo-persistent worlds such as LoL are not accounted for. R. A. Bartle's definition of a "virtual self" has been adopted in definition herein, but the uniqueness criterion have been dropped. Since time and space are not elaborated on the definition in R. A. Bartle, it can be said to describe a persistent communication technology, that is, including virtual worlds, but also including technologies such as GDocs.

Through literature review, Bell and Robbins-Bell (2008) offer the definition of "a synchronous, persistent network of people, represented as avatars, facilitated by networked computers." The term " synchronous" in the definition refers to synchronous communication. Although this seems to be similar to the real-time property, synchronous is only applied to communication in their definition. The real-time property specified herein requires real-time interaction, which includes communication. The term "synchronous" is also ambiguous when referring to communication, for example, Bell and Robbins-Bell (2008) states "a synchronous environment does not require the sender of a message to wait for the other party," whereas a synchronous communication protocol is one where the sender **does** wait for a response. Bell and Robbins-Bell offer a citation for synchronous communication, but the underlying reference refers to sending and receiving messages while users logged on simultaneously, which is irrelevant in determining real-time interaction when both users are logged on. Synchronous communication is said to imply the concept of continuous common time (similar shared temporality in definition herein) and bring about a sense of presence. Bell and Robbins-Bell use R. Bartle (2003)'s criterion for persistence, but add that "a virtual world cannot be paused," differentiating them from video games. This criterion has been adopted in definition herein. A "persistent network of people" is mentioned in their definition, but persistence and a network of people is handled separately in their text; a persistent network of people is not the same as a world that stays in existence, unless worldliness is only defined in function of people. Linked to synchronous communication, Bell and Robbins-Bell refer to social grouping behavior and a primitive form of ecosystem, leaving a "network of people" to mean the social construct. In the definition herein, single-user environments are allowed, making no requirement of social networking, although social networking might be probable in a multiuser virtual world. Bell and Robbins-Bell define an avatar and state that it should have agency (e.g., "a Facebook profile does not have agency beyond its creator"), functioning "like user-controlled puppets. Users command the actions of the avatar, but it is the avatar itself which performs the action." This view would seem to deny an immersive "ego-referenced" (Milgram and Colquhoun 1999) perspective that virtual reality strives for; the reader is referred to Waggoner (2009) for a discussion on this matter. The definition of a virtual self, by R. A. Bartle (2010), was adopted in definition herein. The criterion "facilitated by networked computers" serves to ensure an environment simulated by computers is being referred to and that those computers are networked. The definition herein does not require multiple users or networking.

Girvan (2013) states a virtual world to be: "a persistent, simulated and immersive environment, facilitated by networked computers, providing multiple users with avatars and communication tools with which to act and interact in-world and in real-time." The definition is compiled through literature review, but unfortunately the sampling is heavily biased towards Second Life (Spence 2008) with 47 out of 68 surveyed articles referring to Second Life. The definition herein agrees with many of the properties in this definition, but "immersive" is identified as a qualitative property that is subjective. As with the case of a net-VE above, the definition herein does not require multiple users or networking. The definition herein is similar to the one from Girvan, in the sense that action and interaction are separated. Girvan does not define shared time or space, which is especially problematic when dealing with video games, instances, or ad hoc networking.

Overview

Semantics

It is important to clear up the semantics surrounding the term "virtual world"; perhaps one reason for the lack of definition is a language problem. The word "virtual" can be used to mean "being such in power, force, or effect, though not actually or expressly such" (Dictionary.com 2015, "virtual"). This leads to an interpretation of, for example, a "virtual world of electronics," that is, there

is almost an entire world of electronics or an imaginary world consisting entirely of only electronics. The meaning of "virtual" related to computers can be defined as "temporarily simulated or extended by computer software" (Dictionary.com 2015, "virtual"), leading to usages such as a computer-generated visualization of the digital world of electronics or a simulation of a world. The word "temporarily" in the definition can be justified by the fact that it is nearly impossible to create a truly persistent world. This article shall concentrate on the lattermost meaning of a virtual world, being a world simulated by computers, ruling out the imaginary. In popular discourse, when dealing with mixed reality, it is sometimes helpful to regard the system as "a virtual world overlaid on the physical world" (Lankoski et al. 2004), which can be understood as the world of the virtual, that is, those components that are virtual, in contrast to physical. And lastly, "the word 'virtual' has come to mean anything online (as in 'virtual money')" (Schroeder 2008), so the property of being online is added to the study. By definition, the term "online" means "with or through a computer, especially over a network" (Dictionary.com 2015, "online"), implying virtual and networking.

According to Qvortrup (2001, p. 26), the term "world" refers to "the all-encompassing context for the totality of human activities and experiences." Creating such a world might prove impossible. By creating a virtual world, an allegory of the physical world is modeled or simulated. Oddly enough, "world" is not equal to a planetary world, for example, a virtual world can consist of one or more planetary worlds as in EVE Online (CCP Games 2003). A difficulty in obtaining a definition lies in quantifying the "world" of a potential virtual world, that is, determining if the world qualifies as "worldly" enough. Herein, it is assumed that a world is an environment that consists of people, places, and things, sharing time and space.

Virtual (Simulated) Environment (VE)

For the purposes of this article, a VE is considered to be minimally one, that is, "wholly synthetic" (Benford et al. 1998), simulated by a computing device, and supports the least spatial property of containment (Benford et al. 1998). Milgram and Colquhoun (1999) clarify that a VE is one "which must necessarily be completely modeled in order to be rendered"; contrary to the real (physical) environment over which "the computer does not possess, or does not attribute meaning to, any information about the content."

It should be noted that there are several abstractions of simulation possible within a computing device, for example (in general), the micro instructions of the CPU simulate instructions of the CPU or architecture, which in turn simulate assembly or higher level languages, which in turn simulate the operating system of a computer, and which in turn can simulate the software engine simulating a VE. If a technology can provide for one or more (MANY) "data spaces" (Nevelsteen 2015), then the loaded state in MANY data spaces can possibly constitute a VE. It is possible to have one or more environments, nested in other environments (e.g., multiple software running on the OS); a virtual world is then a specialization of one or more VEs. This logic is counter to the initial choice of words by R. Bartle (2003), who found "world" more encompassing, because he found it "not so easy to see how you could have several worlds within an environment" (Combs et al. 2004, #9). Of course, when Bartle was creating MUD (Bartle 2003), the science fiction universe of EVE Online did not exist, that is, many planetary worlds in a science fiction space odyssey.

In the updated definition by R. A. Bartle (2010), he specifies that a virtual world should be "automated," implementing a "set of rules (its physics)". The property of a virtual world being automated is captured here by referring to a simulation, where the simulated environment has its rules or physics.

Properties of the Definition

In each section below, individual properties found in the definition of a virtual world are detailed.

Simulated (ST) and Virtual Temporality (VT) Similar to simulation, there are several layers of abstractions present when examining temporality in computers, for example, the internal hardware might run at a particular frequency (a number of cycles per second, Hertz); computer programs are perhaps triggered according to an internal clock; and the operating system might have another abstraction of time, that is, there can be an arbitrary number of abstractions of time.

If the internal clock frequency is referred to as hardware temporality, then next level up from this can be referred to as ST; a computerized clock (usually at an accuracy of milli- or nanoseconds) that emulates "real-world" (Zagal and Mateas 2007) time. Software in the computer, making use of ST, uses the current time of the clock (i.e., objective time (Nevelsteen 2014), e.g., 5 am). The computerized clock can be altered independent of real-world time, since it is simulated. Since instrumenting real-world time is often wrought with instrumentation error, the computerized clock is usually not exactly equal to real-world time. And so, real-world events are recorded according to ST as they enter the system.

A software package running in a computer will run according to ST, but can provide another abstraction of time, which can be used by its loaded state, that is, the abstracted time for the loaded state can be altered independently of the computerized clock. The abstraction of time in the loaded state can be referred to as VT, that is, a simulation of temporality in the loaded state relative to the ST of the computer system. Entities in the loaded state making use of VT use either the elapsed time (i.e., subjective time (Nevelsteen 2014), e.g., 3 s) relative to the ST or the current virtual time (i.e., objective time). It is precisely VT that allows the state to be persisted to storage and reloaded, or time in the environment to be paused.

Shared Temporality (1T) Interacting agents, HA or SA, can cumulatively share abstractions of time (their timelines overlap) together simultaneously: real-world, hardware, ST, or VT. 1T means agents are able to share simultaneously real-world and exactly one (ONE) VT, with other agents or entities they are acting upon.

Shared Temporality requires: VT.

Real-time (Rt) When describing a virtual world as Rt (not turn-based and not tick-based games, where players must wait for other players to complete their actions before a new round can begin (Zagal and Mateas 2007)), it implies a world where:

- Players can perform actions simultaneously (Wikipedia 2015b) (the synchronous communication mentioned by Bell and Robbins-Bell (2008) is a subset of this interaction).
- The game world is available and action immediacy is part of the game design (Zagal and Mateas 2007).

It should be noted that Rt is not the same thing as a game with real-time computing constraints; a Rt game is contrary to turn-based, whereas a game with real-time computing constraints must complete computations before certain time deadlines. Although latency reduces the feeling of a game being Rt (Zagal and Mateas 2007), massive amounts of latency do not suddenly keep an environment from being a virtual world, just a very slow one, for example, massive space battles in EVE Online have been known to reduce graphics to a slideshow of images (Drain 2008). Performance is an issue for virtual worlds, but missing deadlines do not constitute system failure as in real-time computing.

Virtual Spatiality Aarseth (2001) states that "computer games are allegories of [physical] space." This is similar to the feature, determined by Singhal and Zyda (1999), that net-VEs provide a "sense of space" for all participants. And, similar to what Raph Koster refers to as a "spatially based depiction" of a VE (Combs et al. 2004, #33), Benford et al. (1998) have classified a scale of spatiality, with "containment only" on one end of the spectrum and a "shared spatial frame" (e.g., a Cartesian coordinate system) on the other, having identified "fundamental physical spatial properties such as containment, topology, distance,

orientation, and movement." Movement is an important factor in VT (Benford et al. 1998), for example, in MUD you move through seemingly continuous space (Qvortrup 2001, p. 28) but in discrete steps. In a graphical world, the equivalent would be moving from pixel to pixel in the frame of reference.

Shared Spatiality (1S) Singhal and Zyda (1999) describe "a shared sense of space" such that: "all participants have the illusion of being located in the same place, such as in the same room, building, or terrain. That shared place represents a common location within which actions and interactions can take place. The place may be real or fictional." Note that the description does not exclude single-player games (i.e., technologies with just ONE human agent and SA), even though the net-VE, by Singhal and Zyda (1999), is described as a multiple user systems. The description is problematic for two reasons: First, telepresence, where users see into each other's physical space, is included in the set of net-VEs. If the definition herein is for a "pure" virtual world, then "the place may be real" should be excluded. Second, "the same place, such as in the same room, building, or terrain," is too restrictive. If "the same place" can be understood as the same virtual world, with (possibly multiple) different terrain and physics, then this part of the description is OK.

Benford et al. (1998) state that "Logically, the shared space in which a cooperative activity occurs can be defined to be those aspects of the system which are independent of any single participant or group of participants and which are agreed on by the participants." This description is problematic, because it is dependent on the architecture serving the virtual world; if 1S is to be "independent of any single participant or group of participants," then having a single participant or group of participants hosting the virtual world is not allowed. In definition herein, P handles this aspect.

Shared Spatiality requires: VS and 1Sh.

One Shard (1Sh) Closely related to architecture, technologies can be examined to see if they are contained within exactly one (ONE) shared data space, ONE shard ("an Ultima Online fiction to explain how come there are multiple copies of a supposedly single world" (Bartle 2003)), rather than MANY. Two ways, to partition a VS to allow for scalability, are regions and shards (Liu et al. 2012; Dionisio et al. 2013). Using regions, the VS is divided into static or dynamic areas, with each area handled by a different group of servers; players can still move throughout the entire VS. With shards, players are divided up into groups and assigned to a unique copy (a shard) of VS, with each shard handled by a different group of servers; players are prohibited from moving between shards. Shards are copies of the same VS that do not synchronize with each other. Note that a shard can be divided up into regions. To examine for the presence of 1Sh, technologies must be examined to see if players share a common data space; with regions players still share VS, with MANY shards, they do not.

Things or Phenomena Simulating things or phenomena using an object-oriented paradigm means implementing in software a basic game object ("The collection of object types that make up a game is called the *game object model*. The game object model provides a real-time simulation of a heterogeneous collection of objects in the virtual game world" (Gregory 2009, original italics).) with the most trivial needed properties (e.g., position, orientation, description or visual representation) and deriving more advanced game objects by adding functionality or specialization to the derived game object. It should be noted that even entities, such as the ground to walk on or water, might be implemented as a single or collection of game objects. For environmental effects such as lighting or heat, that have a source, but where only the effect is modeled, the effect is often attributed to the environment, for example, the sun produces heat, but the sun is not modeled, only the effect of temperature on other game objects. A world will contain both ephemeral things, such as spoken words, and nonephemeral things, such as rigid bodies. Supporting the nonephemeral requires the world to support P.

Things or Phenomena requires: SA.

Many Human Agents (HA) An environment with exactly zero (ZERO) humans can be considered and would be the likeness of a pure simulation, for example, an MUD where no players ever connect. Examining for support of one, two, three, four . . . and an increasing amount of humans leads to a subjective debate on how many humans is enough for an environment to be considered a virtual world, for example, R. A. Bartle (2010) estimates that 100,000 players would be enough to constitute a massive world by today's standards. This property is generalized as support for MANY HA.

Many Software Agents (SA) Because a virtual world is a simulation, one can attempt to simulate HA. Van de Velde (1995, original italics) states that "The concept of *agent* refers to a system that can be differentiated from its environment and is capable of direct and continued interaction with that environment. Such a system 'exists' in its environment and has with it an observable interaction, which is called its *behavior.*" Shoham (1997, pp.271–272) has defined a *software agent* to be one "that functions continuously and autonomously in an environment in which other processes take place and other agents exist. [. . .] The sense of 'autonomy' is not precise, but the term is taken to mean that the agents' activities do not require constant human guidance or intervention." If VT is supported, agents that activate at a regular interval are considered running continuously. It is possible to run agents off other temporalities, but in order to be able to persist the state of the agent and maintain a pure virtual world (contrary to mixed reality), VT is required. According to Russell and Norvig (2010, p.39), an agent that lacks autonomy "relies on the prior knowledge of its designer rather than on its own percepts [. . .] A rational agent should be autonomous – it should learn what it can to compensate for partial or incorrect prior knowledge," that is, autonomy assumes learning. The more relaxed definition of an autonomous agent, by Shoham (1997), is adopted here which does not assume learning. According to Russell and Norvig (2010, p. 39), the most simple agents possible are simple reflex agents, which "select actions on the basis of the current percept, ignoring the rest of the percept history." It is through SA that if a virtual world has ZERO users, the simulation will produce events, that is, develop internally.

Software Agents requires: VT.

Virtual Interaction (Ix) "The concept of 'interaction' generally means 'exchange', 'interplay', or 'mutual influence'" (Qvortrup 2001, p. 34). It is important to make the distinction between the exchange of interaction and the "to act upon" or "react to a stimulus," for example, users act upon user interface entities and a player might react to the stimulus of heat or gravity. In order for exchange to be possible, agents other than humans must be capable of interaction, with for example, SA. This property means the user can both interact with people (Girvan 2013) (other HA in the virtual world) and "interact" with the world (Girvan 2013; R. A. Bartle 2010) (interact with SA and act/react to things and the environment). Both the "a way to communicate" and "a way to share," referred to by Singhal and Zyda (1999, p. 3), is not handled separately, but categorized here under Ix.

If two virtual entities are to have interaction, they must have virtual proximity (Qvortrup 2001), requiring both the 1S and 1T from above, that is, they must share at least one abstraction of time and 1Sh.

Virtual Interaction requires: SA, 1S, 1T, and 1Sh.

Nonpausable (nZ) There is a subset of Rt games that have an "active pause system" (Wikipedia 2015b). For games that support VT, this means players (operators should be able to pause the system for maintenance) can actively choose to freeze VT relative to real-world time. For nZ, technologies are examined for the **absence** of an active pause. Bell and Robbins-Bell (2008) consider the nZ property as a part of P.

Nonpausable requires: Rt.

Persistence (P) R. Bartle (2003) states that a persistent virtual world "continues to exist and develop internally even when there are no people interacting with it." The criterion that a virtual world should "develop internally" is handled by

SA, which constantly alter the world (e.g., as in MUD0). Later, Bartle revised his persistence criterion, removing the need for internal development, stating: "if you stop playing then come back later, the virtual world will have continued to exist in your absence" (Bartle 2010). Bell and Robbins-Bell (2008) use Bartle's original criterion, but interpret persistence to differentiate between video games and virtual worlds on the basis that "a virtual world cannot be paused." Pausing is handled by nZ. Bartle's criterion that the world must "continues to exist" can be referred to as *world persistence* (Nevelsteen 2015), that is, the world continues to exist and is available to the players when they want to access it. To ensure world data is not lost in the event of system failure, the system must support *data persistence* (Nevelsteen 2015).

It is also possible to discuss persistence of the game from a cultural perspective (e.g., events and activities in the game world which do not "reset" (Keegan 1997; Brennan 2009) or are not interrupted by real-world events, like bathroom breaks), but these concepts are beyond the perspective of this article.

The problem with world persistence is that it can be simulated (i.e., pseudo-persistence (Söderlund 2009)), without raising awareness to the player. If the world is made available to players at all times they want to access it, it is seemingly always in existence; a straightforward way to achieve this is to have scheduled play times around down times (Nevelsteen 2015). World data can be loaded and made available at specific times when players, relevant to that data, are playing (Söderlund 2009). In a single-player game, events can be generated to simulate the passing of time during which the game was actually shutdown (Wikipedia 2015a; Nevelsteen 2015). A straightforward way to avoid needing data persistence is to simply have no data to keep track of.

VT is precisely what allows the loaded state to be persisted to storage and reloaded easily; without the abstraction, the world's time would freeze during storage, suddenly rewinding on a rollback or fast-forwarding to the current real-world time on load. Hybridity is possible, but then the world is mixed reality.

Many Avatar (Av) Described as "extensions of ourselves" (Qvortrup 2001, p. 26), there are many definitions of the term "avatar." R. A. Bartle (2010) describes an avatar as a "virtual self" where "each player identifies with a unique entity within the virtual world (their character) through which all their in-world activity is channelled." According to Bell and Robbins-Bell (2008), "any digital representation (graphical or textual), beyond a simple label or name, that has agency (an ability to perform actions), presence, and is controlled by a human agent in real time is an avatar." The real-time aspect is handled by Rt. There is ambiguity in the situation where a user, in a single-user environment, has an ego-referenced viewpoint (e.g., in Zork (Supnik et al. 2003), where the player cannot look at themselves, or in some first-person perspectives in 3D environments); if no digital representation is present, do they actually have one? Even without an avatar, SA must be able to react to the presence of the user, that is, some entity. In this regard, R. A. Bartle's definition of the virtual self is superior to that of Bell and Robbins-Bell (2008), since it defines an entity through which presence can be detected and interacted with, rather than a graphical or textual representation.

Although it is often true that virtual worlds assign a unique virtual self to the user, there is evidence that this is not a requirement. For example, in WoW, there are users that purchase multiple accounts and control multiple avatars simultaneously through multiple installations of the game, a technique that has been referred to as "multiboxing" (WowWiki.com 2015). Because multiboxing can be used to override the unique avatar feature of WoW, the definition by R. A. Bartle (2010) shall be used here, but without the uniqueness criterion.

Drawing Conclusions

The aim of this work is not to express a value of how virtual-like or world-like a virtual world is,

but to find a definition that delineates what is and is not a virtual world, for example, a 3D virtual world with multiple players, a vast many places to visit, totally immersing each player might feel much more worldly than an MUD, but the definition should not exclude an MUD from being a virtual world. In this section, all properties are assembled into the definition herein.

Real-Time Shared Spatiotemporal VE VT ensures the world has its own time, independent from other times. A virtual world can be built based on ST (without VT), but all events related to ST are subjected to be rewound or fast-forwarded, in the case of rollbacks or downtime, respectively. Such a world, however, would not be purely virtual. VT works together with P, ensuring that events persisted to disk are independent of ST, that is, VT can be translated along the timeline relative to real-world or ST, without effecting time-based in-game events. The Rt property excludes turn-based, tick-based, and any other technologies that do not allow users to simultaneous interact with the world. 1T and 1S ensure that the VE conforms to a spatial representation with the likeness of a world and that it is shared by the user of that world.

Shared Spatiality Within One Shard If a technology has more than one data space, 1Sh dictates that those spaces must be merged at one point or another for them to be considered one virtual world; each other copy/shard is considered another world. The question at hand is how to deal with instances, that is, are they part of the virtual world or not? A solution is to judge each shard on its own merits as to whether it classifies as a virtual world or not. An instance can be considered a temporary shard (a copy of a space to which a group of players is assigned), but not a virtual world, if it does not support the required properties, for example, P. In Diablo (Blizzard Entertainment 1996), the virtual lobby is not a virtual world, because it lacks properties such as VS. And the world instances are not virtual worlds either. If the world instance would constantly synchronize with the virtual lobby, the lobby would be providing P for the instance. It is specifically the 1Sh property that allows for a virtual world to be divided in a distributed system, but still remain one world. 1S and 1Sh are combined to determine if technologies have a shared spatiality captured within ONE shard.

Interacting Agents and Things Most technologies support MANY HA outside a pure simulation of a world. R. Bartle's criteria states that a persistent virtual world "continues to exist and develop internally even when there are no people interacting with it." From this, it can be ascertained that the world must support ZERO humans, that is, a world that suddenly has no people connected to does not loose its worldliness. This allows for a virtual world to be created for dogs or other nonhumans. And also, if a world is to continue to develop internally with ZERO humans, the world must support entities that can take action, that is, support for SA determines if there is enough potential intelligence in the system to cause sufficient worldly change. Combined with Ix and the shared temporal space from above, this means humans can potentially virtually interact, in the same time and space, with other HA or SA, or act/react to things and the environment. A technology that just supports HA is a communication technology, but not necessarily a virtual world.

Persistent Virtual World P ensures the world is available to the user when they wanted to access it and where non-ephemeral changes in the world were preserved. P combined with the shared spatiotemporal environment from above ensures that the environment is not a fleeting transient event. To satisfy the criteria by R. Bartle (2003), P is combined with SA. To satisfy the criteria by Bell and Robbins-Bell (2008), P is combined with nZ, a property that seems to effectively segregate virtual worlds from video games, when combined with P. The result of the combination is a real-time environment that is nonpausable where agents produce lasting change.

Virtual Self as Avatar Singhal and Zyda (1999) define a net-VE as a multiuser environment, with each user represented as an avatar; users need a representation through which other users can detect presence and interact. Although it might simplify the definition, no assumption is made here that a virtual world is required to be multiuser, so a single-user environment is still acceptable. The uniqueness criterion for a virtual self has been dismissed on the grounds that multiboxing does not alter the worldliness of a virtual world.; Av is the virtual entity which R. A. Bartle has defined as a "virtual self," with the uniqueness constraint dropped, so that agents (HA or SA) have something to interact with. If MANY avatars are present, at least one avatar must be present in the shared spatiotemporal environment from above.

Discussion and Conclusion

Properties not used can instead perhaps be use to distinguish between different virtual worlds, rather than classify a virtual world. Girvan (2013) offers the properties: "3D, educational, goal orientated, graphical and user-generated content." Some additional properties not mentioned in the analysis are number of players, theme (e.g., fantasy, science fiction), strategy type (e.g., RPG, PvE, PvP), and in-game communication possibilities (e.g., chat, VoIP).

Milgram and Colquhoun (1999) present a continuum for mixed reality, between the virtual and physical. If the VT, VS, SA, Ix, or Av have been "mapped" to a physical counterpart, then the world should fall on the continuum in between the pure virtual and physical. Note that because WoW makes use of both ST (e.g., for the day/night schedule) and VT, to be precise, that would make WoW not purely virtual, that is, a mixed world.

If the provided definition herein proves to not be future proof, properties can be added and the definition can be updated to classify future technologies.

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Virtual Worlds

▶ Virtual Reality Systems, Tools, and Frameworks

Virtual/Augmented Reality (VR/AR)

▶ Imagineering Ceramic Pottery Using Computer Graphics

Virtuality Continuum

▶ Mixed Reality

Vision System

▶ Facial Recognition and Emotion Detection in Environmental Installation and Social Media Applications

Visual Accessibility in Computer Games

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Synonyms

Accessible game development; Audio description; Visual accessibility technologies

Definition

Visual accessibility in computer games refers to techniques used to convey or enhance understanding of visual information, particularly for blind or partially sighted individuals. Visual information describes any narrative or gameplay information which is conveyed to the player in a visual format such as text or images displayed on a screen.

Introduction

Over the years, computer games have become an increasingly popular form of entertainment (Cairns et al. 2019). Games have the capacity to connect people across the world whether they are playing together in a multiplayer environment or discussing their varied experiences of a single player game. However, despite the increased popularity of games, many of them remain inaccessible to large portions of the population (Cairns et al. 2019). There are many factors which may make games inaccessible to users ranging from controller design to reliance on visually conveyed information ("Game accessibility guidelines" 2012). Games are intended to be enjoyed by as many players as possible, and when accessibility concerns prevent players from playing a game, it is the responsibility of developers to continue to improve and iterate on their designs to overcome these obstacles so that everyone is included (Cairns et al. 2019). Many accessibility options exist and the field of accessibility has received increased attention in recent years from both game development studios and games user researchers (Cairns et al. 2019). This increased attention has led to further innovations and the development of new accessibility options to overcome a variety of obstacles (Cimolino et al. 2021).

The adoption of these accessibility options varies considerably across the games industry (Porter and Kientz 2013). Despite the existence of these options, many games continue to prove inaccessible to players (Kulik et al. 2021). Conversely, some games focus extensively on accessibility and push the boundaries of current accessibility options by developing new options or refining existing options (Morris 2021; Ombler 2021). In the case of visual impairment, key developments in accessibility have focused on relaying visual information through sound with spatial audio and narrative descriptions, and touch with haptic feedback (Fiadotau 2018; Kelly and Şengün 2022; Stevens 2018). Additionally, accessibility options vary depending on the hardware and software available to players based on whether they are playing games on a dedicated gaming console or a computer. Computers offer additional software options such as screen readers, but these programs are not always compatible with games and require additional attention for compatibility. Fortunately, in recent years, there has been an increased focus on making games more compatible with assistive technologies such as screen readers so that players can continue to rely on these tools as they play. Alternatively, consoles readily provide haptic feedback through game controllers, but this option can also be acquired for computer games with a compatible gamepad controller.

Spatial Audio

Spatial audio refers to audio processing algorithms which deliver sound-based cues in a way that reflects a three-dimensional (3D) environment (Yadegari et al. 2022). This method of providing the information is especially useful for visual accessibility. This spatial audio application has recently been explored on consoles in *The Last of Us: Part II* (Kelly and Şengün 2022). In this game, players can detect enemies in their environment with a system similar to echolocation. Players make a ping centered on their location, which expands and returns as it hits characters in the environment (Ombler 2021). Depending on where these enemies are located in relation to the player, the position of the returning ping in the soundscape will change to indicate direction, and its pitch will change to indicate the distance. In this way, players know how many enemies are in their vicinity, whether they are near or far, and whether enemies are above, below, or on the same level as the player

(Ombler 2021). Given the importance of precise player and enemy positions across many genres of games, conveying this information in a variety of ways is vital to ensure that games remain accessible to players with visual impairments.

In computer games, a recent example of advances in the development of spatial audio can be found in *The Vale: Shadow of the Crown* (Reeves 2021). In this game, Unity tools originally developed to create spatial audio for virtual reality (VR) games are leveraged to create "3D soundscapes" (Reeves 2021). Taking this a step further, *The Vale: Shadow of the Crown* forgoes the use of visuals entirely and instead uses spatial audio to immerse players in the environment and convey vital information for gameplay such as the timing of enemy attacks. Spatial audio has a diverse range of applications, and given the recency of this development as an accessibility tool, it is an area which warrants further research to determine new applications and refine existing ones.

Narrative Description

Narrative description is another method used for conveying information in a visually accessible way and refers to any form of visual accessibility which relies on delivering narrative information through speech or other forms of audio. Depending on the needs of the game being developed, there are multiple ways for narrative descriptions to be implemented. Two of the core methods for this are audiogames and described audio.

Audiogames

An audiogame is any game that forgoes the use of visuals and instead relies entirely upon audio to deliver information (Fiadotau 2018). Some methods of delivering information solely with audio include voice-acted dialogue, spatial audio, and describing game elements with a narrator rather than text captioning (Fiadotau 2018). One recent example of an audiogame is *The Vale: Shadow of the Crown* (Morris 2021). In this game, the only visual displayed on the player's screen during gameplay is a set of floating lights in an abstract background which has no relation to any of the game's content (Morris 2021). The narrative is entirely voiced, and spatial audio is used to immerse the player (Morris 2021; Reeves 2021). On the main menu, selectable options are displayed in text, but they are also read to the player whenever the option is being interacted with, and, while playing the game, interactions such as movement and swinging weapons are described to the player along with the actions the player must take to perform them.

Given that audiogames rely solely on audio, all of the systems present in these games must revolve around creative uses of game audio. The audiogame approach of audio first rather than visuals followed by visual accessibility options to translate that experience into audio has the potential to create more dynamic experiences for blind and partially sighted users. However, it is vital that these games' development is guided with input from the blind and partially sighted community to account for the biases of sighted developers and ensure that the intended experience is delivered (Morris 2021). In the case of *The Vale: Shadow of the Crown*, this was accomplished through a collaboration with the *Canadian National Institute for the Blind* (CNIB) (Morris 2021).

Audio Description

Audio description (AD) is the practice of having a narrative describe visually displayed elements of a scene in words so that blind or partially sighted users can experience the full range of information in a scene. Many games rely upon a mixture of audio and visual information, and, in these cases, AD is an effective method for ensuring that all players have equal access to this information (IGDA GASIG 2020). While AD has not yet been adopted as a common strategy for visual accessibility by game developers, community-driven movements have stepped in to fill the gap (IGDA GASIG 2020). Notably, *The Transcribing Games Project* is working on creating AD transcript guides for cutscenes and various encounters in a variety of games, including *God of War* and the *Gears of War* franchise (SightlessKombat

2022). This initiative aims to demonstrate the efficacy of AD as an option for visual accessibility with the hope that it will be adopted in the games industry similarly to how it has already been adopted as a standard accessibility option in film and television (IGDA GASIG 2020). Interest in audio description for games is still in the early stages, but with some large studios beginning to take an interest, this may grow to become a part of visual accessibility in games in coming years (IGDA GASIG 2020).

Despite the many potential benefits of AD, these benefits are based entirely on how effectively the AD is created and delivered (IGDA GASIG 2020). For example, with the wrong tone or word choice, the meaning of visual elements in a scene may be transformed in their translation into AD and the message the player takes from the scene may differ from what was intended or the player may miss out on vital information. As such, it is important that audio description be thoroughly tested throughout the design process and that user testing is guided by the experience of blind and partially sighted users (IGDA GASIG 2020). As in all cases of accessibility, companies must work with and learn from the experience of members of the communities which these options are intended to support.

Software Accessibility

There are many different types of software developed for the purpose of accessibility, allowing a user to create a more personalized experience to assist in overcoming any obstacles they may come across when using various forms of computer software. Here, we will explore some of the types of programs developed for visual accessibility, along with some of the limitations and difficulties that can occur when using them or developing them.

Screen Readers

Many software tools exist to assist people with visual impairments that can and are used with video games. Some of the most notable tools in this area are screen readers. This type of software is able to read the text provided by web browsers, email clients, and other computer software and output them to the user, usually as audio or by text to a braille reader (American Foundation for the Blind 2020). Currently, there is a trade-off when adding user interface (UI)-text-to-speech features to the software. There are APIs dedicated to feeding text to third-party screen readers that games can access on desktop platforms, such as the. NET UI Automation API (Microsoft 2021) and the OS X Accessibility API (Apple 2015). However, not all platforms have such dedicated systems. As such, developers should consider what platforms they are developing for and investigate existing interfaces that can be leveraged for each platform in both hardware and software before attempting to create in-house solutions.

It is important to consider design principles to ensure compatibility with various platform specific software and the effectiveness of designs in delivering accessible user experiences. *Microsoft*, for example, has created official guidelines for ensuring effectiveness and compatibility with external screen readers (Microsoft 2021). These guidelines provide recommendations on introductory principles of what elements should be included as well as when and how they should be implemented (Microsoft 2021). There are many kinds of user interface elements, but perhaps the most important guidance that can be provided is to include text alternatives to describe each UI element's functionality. For other objects, such as images or icons, it is unnecessary to describe the type of object being selected, and developers can instead focus on describing the function of each element. Accordingly, for any UI elements made with a markup language, developers should ensure that the IDs and attributes of each object are unique. These unique identifiers will then help assistive technologies track changes to existing objects.

Magnifiers

It is important to note that visual impairment has many dimensions, such as acuity and color, and depth of field. Accordingly, software-based vision aids are frequently used in visual accessibility to accommodate the wide range of experiences

associated with visual impairments. One such feature is magnification software (American Foundation for the Blind 2020). With this software, users can select a region on their screen to increase the size of visual elements within so that they become easier to read. Magnifiers are available as a standard option on most desktop platforms and can be used in conjunction with gaming software (Microsoft 2022a, b; Apple 2020). Frequently, magnifying software will require the game to be in a windowless fullscreen or windowed mode to not interfere with game input. While it is always advisable to have in-game text size be variable for player preference, this is another option that can assist in making a game more accessible.

Color and Contrast

Another feature that comes standard on most desktop platforms is color filtering (Microsoft 2022a, b; Apple 2020). Filters change the colors on a screen to a palette specifically designed to make information displayed on the screen more readable for people with the type of color blindness for which the filter is designed. However, some platforms may not have built-in color filters, and developers should take care to check what features are already available on the platforms they are deploying to before considering creating an in-house solution.

Hardware Accessibility: Haptic Feedback

While the previously mentioned features have all been related to software, hardware can also be leveraged to make games more visually accessible. Haptic feedback refers to any kind of feedback conveyed through a sense of touch. Within gaming, this is almost always in reference to a rumble feature on a gamepad, though a few other options exist, such as gamepads that can alter the resistance of certain buttons when pressed (Gartenberg 2021). Haptic feedback is not commonly featured on personal computers that are utilized through mouse and keyboard. There are some mice that include a rumble feature, but these are uncommon. To utilize haptic features on a computer, the best option is to connect a compatible gamepad controller since rumble is a standard feature of these devices.

Given that haptic feedback can be utilized by players who have either limited vision, hearing or both, it can be a valuable tool for providing information to players (Stevens 2018). By altering the pattern and strength of a rumble, a game can provide contextual information such as impending enemy attacks or critically low player health. However, some haptic feedback, like rumbling, can be uncomfortable, distracting, and potentially even painful for some players, so it is necessary to have an option to turn this feature off.

Conclusion and Discussion

There are many different options for making games more accessible for players with visual impairments, but these options are applied inconsistently throughout the games industry (Porter and Kientz 2013). Options all have their specific uses and limitations that should be considered during the game development process to ensure that the final product is accessible to as many players as possible. To ensure that games are as inclusive as possible, developers must learn from established research in accessibility, seek out feedback from players with disabilities, and collaborate with the communities aiming to make their games accessible at every step of the game design process.

Cross-References

- Audiogame
- Spatial Audio and Sound Design in the Context of Games and Multimedia
- Video Games and Accessibility: A Case Study of the Last of Us II

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Visual Accessibility Technologies

▶ Visual Accessibility in Computer Games

Visual Culture

▶ Challenges Facing the Arab Animation Cinema

Visual Effects

▶ Virtual Reality Stereo Post-Conversion After Effects Workflow

Visual Impairment

▶ Audio and Facial Recognition CAPTCHAs for Visually Impaired Users
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▶ Computer Games for People with Disability
▶ Making Virtual Reality (VR) Accessible for People with Disabilities

Visual Literacy

▶ Animation and Neurocinematics: Visible Language of E-motion-S and Its Magical Science

Visual Memory

► Computer Games for People with Disability

Visual Novel

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Synonyms

Bishōjo game; Sound novel

Definition

A visual novel is a form of digital entertainment that consists of text accompanied by mostly static graphics. The reader advances the text, usually by clicking, and is occasionally presented with choices, which may or may not affect the outcome of the story. Despite originating from Japan, visual novels have gained some international recognition, although it remains debatable whether or not they should be classified as video games.

Overview

"Visual novel" is a term that is more popular in the West than in Japan where the genre originates from. In Japan, visual novels are often called *noberugēmu* ("novel game," short for "visual novel game") and, occasionally, *saundonoberu* (sound novels), the latter being a term introduced by game company Chunsoft, which in the early 1990s developed a series of such games for the Super Nintendo Entertainment System. Prior to that, visual novels were developed almost exclusively for the personal computer, which still remains the platform of choice for many visual novel developers.

In Japan, visual novels are often considered a subgenre of adventure games (Koyama 2006: 31). However, due to their reliance on textual narrative which is affected by the reader's choices, visual novels are also close to Choose Your Own Adventure books and, more broadly, can be considered a form of interactive fiction (Yin et al. 2012). However, they have also evolved distinct conventions that set them apart from other similar genres.

One easily recognizable feature is the visual presentation, with most visual novels utilizing a first-person perspective and featuring static or sparsely animated nonplayer characters displayed against an equally static background. Backgrounds represent particular locations within the game world and change as the player character moves about (Galbraith 2011). The dialogue and narrative take the form of text, either overlaying the graphics or displayed in a text-box occupying the bottom part of screen. While their visual style can range from photographic to pixel art, the majority of visual novels favor anime-style esthetics (Bruno 2017) (Fig. 1).

Visual novels also have a less straightforward relationship with player choices than most works of interactive fiction. Whereas in a Choose Your Own Adventure book each choice can shift the story dramatically, choices in a visual novel may have no immediate effect on the narrative, contributing instead to a complex system of potentialities and character relationships that resolves itself toward the end (Fiadotau 2018). For example, in the beginning of *Ever 17: Out of Infinity* (2002), the player, put in the shoes of a visitor to an underwater theme park, is given the choice of either listening to the safety briefing offered by a staffer or listening to a joke told by a fellow visitor, thereby missing the staffer's explanation. While the choice has very little immediate effect, ignoring the joke may prevent the player from reaching the "true" ending of the game due to failing to establish rapport with the fellow visitor.

The existence of multiple endings and especially a "true" ending, which is typically only unlockable after several or all of the other endings have been reached, is another notable feature of visual novels. *428: Fuusa Sareta Shibuya de*

Visual Novel, Fig. 1 A scene from Ever 17: Out of Infinity (2002), featuring typical visual novel elements: static background, anime-style characters, and a text box in the bottom part of the screen

(2008), for example, has a total of 85 endings, only 1 of which is considered the "true" end. On the other hand, some visual novels, such as *Planetarian: Chiisana Hoshi no Yume* (2004), feature no choices at all and are completely linear, therefore only having one possible ending. These are known as "kinetic novels" (Fiadotau 2018), so named after a series of linear visual novels produced by Japanese game company VisualArt's (Fig. 2).

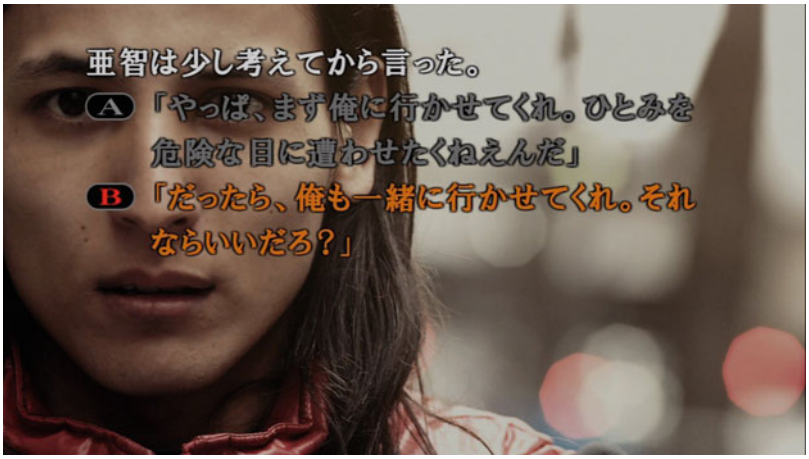
Many visual novels focus on romance, often containing erotic or pornographic elements (Bruno 2017). A particular subset of visual novels, known as *bishōjo* (lit. "beautiful girls") games, feature a male protagonist romancing one of several female love interests, typically culminating in an erotic scene (Sousa 2014). Other visual novels adopt a female perspective on romance (*otome*) or depict male-on-male (*yaoi*) or female-on-female (*yuri*) homoerotic relationships, although these are generally tailored to the tastes of a heterosexual audience (Arunrangsiwed 2015; Nagaike 2010). Some visual novels, such as *Eve: Burst Error* (1995) and *Air* (2001), have been released in two versions, with and without sexual content, in an effort to broaden their appeal. Even when romance is not the central theme, visual novels tend to place a lot of emphasis on communication and building relationships with characters (Bruno 2017).

On a wider level, visual novels, and especially *bishōjo* and *otome* games, are often seen in Japan as part of the *otaku* subculture, which revolves around conspicuous, often defiant consumption of popular culture such as anime, manga comics, and TV series (Sousa 2014; Galbraith 2011).

Significance and Impact

While usually associated with Japan, visual novels have had considerable influence beyond their country of origin. Titles such as *Ever 17: Out of Infinity* (2002), *Clannad* (2004), and *Rewrite* (2011) have been translated into a number of languages, including English, and achieved popularity abroad. This has led to the emergence of original Western visual novels such as *Digital: A Love Story* (2010) and *Everlasting Summer* (2014). Visual novels' focus on choices and relationship building has also inspired Western adventure game developers such as Telltale Games to depart from the conventions of point-and-click adventure games and experiment with more narrative- and character-driven game design (Gravelle 2016).

However, a fundamental question visual novels have raised in the West is whether they should be classified as games at all (Heron 2013: 58). In Japan, visual novels are generally accepted to be



Visual Novel, Fig. 2 In 428: Fuusa Sareta Shibuya de, the player has to make many choices, which can result in a total of 85 endings

a genre of computer games and are in fact called that ("novel games"). Western audiences, however, remain split over the question of whether an occasional choice constitutes enough interactivity to call something a video game. The case of kinetic novels, which have no choices at all, complicates the issue even further – although the absence of choices is not necessarily immediately obvious to the player (Fiadotau 2018). This ambiguity suggests that the notion of a video game is not universal and may be culturally conditioned.

Whether or not visual novels as such are games, they combine well with other game genres. Many popular titles in Japan include story-driven visual novel segments interspersed with puzzles (*Nine Hours, Nine Persons, Nine Doors*), fighting (*Melty Blood*), role-playing (*Princess Waltz*), rhythm gaming (*Symphonic Rain*), and so on.

Due to their simple mechanics, visual novels are also relatively easy to develop. As a result, the genre is very popular with hobbyist (*dōjin*) game developers in Japan (Picard 2013) and is used by indie developers in the West as well.

This ease of development, coupled with the genre's emphasis on textual content, makes visual novels a good vehicle for learning. Commercially released visual novels that incorporate educational elements include *Emit* (marketed as a game for learning English) and *World End Economica* (which introduces many concepts in economics despite not being positioned as an educational game). The visual novel genre has also been adopted by serious games whose purposes range from increasing hospital patients' self-efficacy (Yin et al. 2012) to promoting tourism in rural areas (Kurata 2013). This shows that the range of possible applications of visual novels as a medium reaches far beyond the cultural niche the genre has originated from.

Cross-References

- ▶ Dōjin Game
- ▶ Gamification and Serious Games
- ▶ Indie Game

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Visualization

▶ Tactile Visualization and 3D Printing for Education
▶ Training Spatial Skills with Virtual Reality and Augmented Reality

Visualization Techniques in Augmented Reality

▶ Enhanced Visualization by Augmented Reality

Volumetric Capture

▶ Volumetric Filmmaking

Volumetric Filmmaking

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Synonyms

Volumetric capture, Holographic filmmaking

Definitions

Volumetric filmmaking is an application of volumetric capture technology to filmmaking. Volumetric recording captures the topology of objects in 3D space rather than the projection of 3D space onto a 2D frame. The recording can be viewed from any perspective decided by the viewer at the time of viewing. Thus, in volumetric film, the viewer takes over the director's responsibility for

selecting the *point of view* from which the story is being told.

Introduction

Volumetric filmmaking is an interactive, participatory, and narrative medium enriching the vocabulary and grammar of audiovisual storytelling. Volumetric filmmaking is made possible by the development and democratization of access to volumetric capture technology. Volumetric capture is a recording of topology, rather than a 2D projection, of actors, sets, props, objects, and environments. Volumetric filmmaking is not just a technological innovation, but a new-in-kind audiovisual medium since it changes the role of the director and empowers the viewer in the process of telling and absorbing the story. In traditional 2D and 3D filmmaking, the story is told through a carefully arranged sequence of 2D projections called "frames." In 360 immersive video, the story progresses through series of predetermined spherical projections of the film world. In volumetric filmmaking, the position of the sphere through which the viewer perceives the story is decided by the interaction performed by the viewer at the time of the viewing (Fig. 1). The fact that the viewer is in control of the sphere's position makes volumetric filmmaking a new-in-kind medium.

The first volumetric captures for entertainment date back to 2006, when a point cloud of Thom Yorke of Radiohead was used in a music video for his "House of Cards" song Yorke (2008). In recent years, a diversity of volumetric experiences were created, including Oscar-winning "Carne y Arena" by Alejandro Gonzlez Irritu Irritu (2018), Emmy-winning "Zero Days VR" volumetric documentary film by Yasmin Elayat Elayat (2017), "Terminal 3" by Asad Malik Malik (2018), or interactive fiction narratives such as "Vera" by Krzysztof Pietroszek Pietroszek (2020). Currently, the volumetric filmmaking enters its Renaissance age due to the volumetric capture technology becoming more accessible to filmmakers.

Technology of Capturing Volumetric Data

Despite the name, the volumetric capture used in volumetric filmmaking does not capture the object's volume per se. While technologies such as magnetic resonance imagining or computer tomography allow for capture of the volume of many types of objects, these techniques are not used in volumetric filmmaking due to cost and associated health risks. Rather, volumetric capture records the information about the *topology* of the captured object or person, without any

Volumetric Filmmaking, Fig. 1 Traditional vs. 360 Video vs. Volumetric Filmmaking. In traditional filmmaking, the story is told through a sequence of frames (left). In 360 video, the story is told as a series of static spheres surrounding the viewers (center). In volumetric filmmaking, the sphere is moving at the direction of the viewer (right)

information about the interior. The reconstruction of the topology utilizes two types of techniques: photogrammetry or depth sensing. In practice, photogrammetry is often used for volumetric capture of static objects, such as film sets and props, while depth sensors are used for capture of moving objects or actors.

Capturing Static Objects

Photogrammetry process results in high quality 3D reconstruction at relatively low cost, since the capture can be performed by a single digital photography camera. The process consists of systematically taking many (often hundreds of) photos of uniformly lit object from various angles and at various distances from the object. The setup requires fast shutter (at least 1/250 for handheld capture) and small aperture (at least 1/8 on a typical DSLR) since the goal is to capture images of the object without motion blur or shallow depth of field.

If the object is small enough, it can be placed on a turntable with the camera taking photos at predefined angle intervals corresponding to the object rotation, for example, every two degrees. If the object is larger (e.g., an interior location), digital camera is used to take hundreds of photos from various perspectives. For extremely large objects, such as entire buildings or towns, when taking individual photos is impractical, drone flights can be performed with the camera recording a film, rather than taking individual photos. Using the velocity and the position information about the drone flight to aid the reconstruction of the object improves the reconstruction process. This approach to photogrammetry is called *structure-from-motion.*

Not all objects can be efficiently captured with the process of photogrammetry. Objects that are shiny, and therefore show specular reflections, are difficult to capture. Transparent or semitransparent objects that diffract the light cannot be captured with the photogrammetry method at all.

Most of the photogrammetry reconstruction algorithms take both angle between a pair of images and the color of each pixel in both into account, thus objects with pattern or texture tend to be reconstructed with higher precision. Objects with predominantly convex topology are reconstructed with less error, since the reconstruction algorithms may have difficulties or are incapable of inferring occluded or concave areas of the object, if no sufficient information can be derived from the series of photographs taken.

Many commercial as well as some open-source solutions exist to assist in photogrammetry process Hanke and Grussenmeyer (2002), Spurr (1960). The process of photogrammetry is very computationally intensive, since typically each image is compared, pixel by pixel (or small region of pixels by small region of pixels), with all other images in the series. Until recently, the photogrammetry process could take days on a typical PC. Since the implementation of GPU-compute-shader-based photogrammetry algorithms, the process now takes minutes or hours.

Alternatively to photogrammetry, a static object can be reconstructed using 3D scanner. Laser-based (LIDAR) 3D scanners provide the highest reconstruction quality at high cost. Handheld laser or infrared 3D scanners result in topology reconstruction of the quality similar to or better than photogrammetry but are usually used to reconstruct the object's shape only, without color. Finally, handheld depth cameras, such as each generation of Microsoft Kinect, can be used for 3D scanning and reconstruction, but the resulting object is usually reconstructed with the lower quality than through the photogrammetry process.

The reconstruction resulting from photogrammetry or 3D scanning requires further processing to be used in volumetric film. First, since the reconstructed mesh usually consists of hundreds of millions of vertices, it must be decimated. In case of complex typologies, the standard decimation process may not be sufficient or may introduce topological errors, in which case, a 3D modeler may choose to perform manual retopology of the object. If the object is not uniformly lit (for example, part of the object is in a shadow), a delighting process may also be performed on the object's texture, so that the resulting reconstruction can be properly lighted in the film scene where the object is used.

Capturing Moving Objects

Both photogrammetry and 3D scanning processes, when performed with a single sensor, require the object to be static for the entirety of capture. In consequence, while the techniques result in high-quality reconstruction, they cannot be used in practice for capturing actors or moving objects. To capture actors and moving objects, a system of multiple cameras is used. Since more cameras produce more data and increase the overall cost of the system, low-cost-low-quality volumetric capture systems tend to use fewer cameras (from 1 to 20), while high-cost-high-quality systems use many cameras (from 30 to over 100) and produce petabytes of data.

There exist commercially available low-cost volumetric capture systems that offer a capability of capturing volumetric data of acting performances, or, more generally, moving objects, using a single RGBD sensor (aka depth camera), such as Microsoft Kinect or Moholo camera. Single depth camera recording results in a volumetric capture that can be viewed only from a limited sweet spot of about 10–20 degrees off the angle of the recording. With the advent of a new generation of better quality RGBD cameras, research and development efforts are put toward creating low-cost multicamera capture, and it can be expected that such systems will be widely available in the near future. Current depth camera errors are the main limitation of the RGBD-based approach to multicamera volumetric capture, since it is difficult to register multiple cameras to each other when the pixel positions differ by such a large error.

In RGBD sensors, two technologies are commonly used to infer the 3D position of the pixels: *structured light* and *time of flight.* Both technologies use infrared light instead of visible spectrum light. Structured light entails a specific pattern projected by the camera onto the surface to be captured. Then, the same camera records back the pattern and infers the surfaces' topology from the pattern's deformation. While the technique is easy to implement in a low-cost hardware (e.g., Kinect 360), the pattern deformation does not provide enough information for high-quality reconstruction. Additionally, the pattern projection is prone to errors resulting from environment lighting and the distance of the object from the camera. The second approach, time-of-flight, measures how much time it takes for the photons of the light emitted by the camera to return back to the camera after being reflected by the surface to be captured. This technique results in smaller error that does not increase with the distance from the camera as quickly as it was in the case for the structured light technique. Nevertheless, the technique suffers from errors on edges of the captured objects, because the angle of reflection results in no photons coming back to the sensor. The technique is also sensitive to environmental lighting conditions, when, for example, sunlight floods the scene with infrared light that confuses the sensor.

High-quality, but much more expensive commercial volumetric capture systems, such as Microsoft Meta Stage, or Intel Volumetric Studios, typically utilize an array of tens or hundreds of time-synchronized RGB cameras, thus avoiding the issue of depth-sensor error. The process used in reconstruction of volumetric images from multiple RGB cameras is no different than static photogrammetry and results in individual reconstructions of 3D objects for every frame, typically 30 frames per second. The resulting series of 3D reconstructions, when played as a film, often create a flickering visual artifact, because reconstruction of each frame is done independently from all preceding and following frames. Some researchers are attempting to improve time coherence of the resulting point clouds or meshes, thus addressing the flickering issue.

Serialization

Regardless of the technique used, the resulting volumetric recording is a static or temporal textured mesh. The mesh can be serialized in traditional 3D modeling formats, such as a series of Wavefront Technologies' .obj files. Since separate mesh and texture are recorded for every frame of the volumetric recording, this approach results in very large data, making it impractical for streaming or mobile applications. An interesting approach to this problem is to encode the capture

Volumetric Filmmaking, Fig. 2 Volumetric capture video frame: The top part of the frame provides the rgb information, while the bottom encodes depth information for each pixel of the captured scene

for each camera as a top-and-bottom color video file where the top of the frame provides the rgb information and the bottom of the frame provides matching depth information. This approach is particularly effective for single camera volumetric captures that do not capture the information about all the sides of the object (Fig. 2).

Viewing Volumetric Captures

Rather than project a traditional video recording that captures a projection of three-dimensional reality onto a two-dimensional frame and presents the results in a series of frames in juxtaposition to achieve the desired narrative, volumetric filmmaking seeks to capture and present three-dimensional data on actors, props, and set decoration and presents it as recorded. The way the volumetric recording technology captures and represents reality affects the way the volumetric story is/should/has to be told. Interestingly, regardless of the quality of capture, the playback of volumetric recording does not seem to cause the "uncanny valley effect" (Mori et al. 1970).

Volumetric film can be presented at any point of the reality-virtuality continuum. The films are typically experienced using a head-mounted display, mixed-reality glasses, or through a magic window of a mobile device, but stand-alone multiviewer volumetric displays also do exist. Large-scale multiviewer presentation is also possible using CAVE systems, or transparent foil projection. Fog displays combined with projection mapping allow for large-scale multiangle volumetric viewing but offer low visual fidelity.

Depending on the type of display used, volumetric films may be viewed at a wide range of scales, from miniature to life-size. Current limitation in the field of view (FOV) of augmented reality displays pushed volumetric filmmakers to search for meaningful, smaller than life-size presentation scales. One idea is to present miniature experience on a tabletop https://www.rsc.org.uk/events/magic-leap-seven-ages-of-man (2019) or floating in air in front of the user (Pietroszek et al. 2019). True to life experiences designed for AR viewing usually adapt the narrative itself to the limitation of AR displays' FOV. The field of view of user is larger than field of view of the AR device. The search may be directed with visual or auditory cues. Upcoming technological advances that increase the field of view in AR presentation will address this limitation.

When presented in virtual reality, volumetric filmmaking typically involves more than rendering of a volumetric capture of an actor. Sometimes, an entire set is reconstructed through a process of photogrammetry, creating a walkable immersive experience.

Interaction in Volumetric Film

Unlike traditional film or 360 video, a volumetric film is inherently an interactive, explorable, and three-dimensional experience (Fig. 1) that can be viewed from any point of the reality-virtuality continuum (Milgram et al. 1995). As an interactive medium, volumetric filmmaking differs *in essence* from the traditional filmmaking and 360 video that are passive media. Moreover, volumetric film attempts to directly simulate the visual input of the real world. It is conceivable that in a far-enough future, with sufficient technological advancements, human perception will be unable to distinguish the visual and auditory stimuli offered by a volumetric film from the visual and auditory stimuli provided by the reality itself. Such medium can no longer be called to "mediate."

Navigation

Navigating the volumetric film's world takes advantage of the techniques that were developed for virtual environments navigation and exploration, including real-time movement tracking, redirected walking (Sun et al. 2018), or various gaze-based or pointing-based teleportation techniques (Pietroszek 2018a). A scene in a volumetric film may limit the viewers' movement into predefined walkable area, or allow free-roaming within a world larger than the exhibition space. In the latter case, volumetric filmmakers typically try to avoid teleportation, since it takes the user out of the immersion and results in temporary disorientation right after the move. Recent advances in redirected walking, such as dynamic saccadic redirection-based redirected walking (Sun et al. 2018), promise that in a near future there will be no need to have the viewing space as large as the walkable scene space.

Interaction with Objects

Some volumetric films disallow any interaction between the viewer and the objects in the film, assuming the "direct cinema" approach, in which the viewer's presence in the scene should remain unnoticed as if the viewer was a *fly on the wall* (Nichols 1983). Few existing examples (Szilak and Tsiboulski 2018) break this "rule" and allow the user to interact with at least some of the objects in the scene. Interaction usually uses virtual hand metaphor (Pietroszek 2018b) through freehand tracking or a controller. No volumetric films to date use distal pointing or raycasting techniques for object selection and manipulation.

Interaction typically takes a form of object selection and *limited* manipulation of the objects, such as picking up a cup or rotating a dial. Actions are usually diagetic, and therefore exclude scaling or other modifications that are not possible in the real world, unless the story happens in a fictional world where such actions are possible. In few examples, the interaction is further enhanced by cloth or soft-body simulation applied to some objects (curtains, carpets, and bags) (Pietroszek et al. 2019).

Interaction with objects is often supported with pseudo-haptic or passive-haptic feedback. 3D printed versions of the film props may be used and tracked to provide close tactile resemblance of the prop's shape. Virtual walls and fixtures may be mapped to physical walls and fixtures to provide impenetrable navigation barrier or to increase immersion.

Embodiment

Similar to object interaction to date, very few volumetric films provide the viewer with an embodiment. Sometimes, the embodiment is limited to the rendering of hands (Szilak and Tsiboulski 2018). The embodiment may also be implicit, for example, as a reflection in the mirror that the viewer may look at. Whether the embodiment is implemented is often related to the point of view the story is being told from. In the first person stories, where the viewer is assumed to be one of the characters in the story, the embodiment may be provided (Szilak and Tsiboulski 2018). In the stories told from the third person perspective, the viewer embodiment is usually not provided.

Use of Spatial Mapping

Volumetric filmmaking often takes advantage of spatial computing, especially the 3D mapping of the environment. Some volumetric films use *augmented virtuality* (Milgram et al. 1995) by

mapping the set decoration and props onto physical elements of the installation. Volumetric captures may use physical chairs, tables, walls, or props to sit on, hide behind, jump onto, or lean on. For example, a chair displayed as a part of the set decoration of the current scene may be "good enough to sit in," to echo a line from an Ivan Sutherland's seminal "Ultimate Display" essay (Sutherland 1965), since it is mapped to a motion-tracked physical chair.

Volumetric Storytelling

The inherent interactivity of volumetric filmmaking affects its cinematography, montage, and the way the story ark is constructed. In traditional filmmaking, the story is told the way the director envisions it. The director starts by creating a unique vision of the screenplay, with its mood, color palette, pacing, acting style, cast, mise-en-scene, and, no less importantly, cinematography. Cinematography provides the director with an ability to decide a *point of view* that translates their vision onto the screen. Cinematography is designed in close collaboration between the director and the director of photography and consists of the choice of the shot sizes, camera angles, camera movements, and the spatial relationship between the actors' position and the camera (aka blocking). In postproduction, the director's vision is further revised through a myriad of montage techniques at the disposal of the film editor that affect the film's pacing, tempo, atmosphere, and the meaning and emotional impact of a sequence of frames through phenomena known as Kuleshov's effect (Barratt et al. 2016).

The language of 360 video builds upon the language of traditional filmmaking. However, due to the technical limitations of the current 360 cameras and their effects on human physiology and perception, only a subset of the cinematic language of traditional film finds its direct applications in 360 video production. For example, accelerated camera movements are not advisable, as they cause cyber sickness. Close-up is not possible since it results in the unnatural size of objects and actors. Cut disorients the viewer and is perceived as a jump cut rather than a time-compression mechanism. In response to the above challenges, 360 video expanded or modified the traditional cinematic language. Attention directing cues, replacing a cut with fade-out/fade-in, and long establishing takes that allow the viewer to orient themselves in the new environments are just few examples of how cinematic language evolved to accommodate the specificity of the 360 video as a storytelling medium.

Both traditional film and 360 video, once completed, constitute a finished piece of art. Even though the viewer's context and the passage of time impact its interpretation, the film remains essentially the same, a completed creative artifact.

A differentiating characteristic of a volumetric film is that it allows the viewer to perceive the story from a *point of view* of their choosing rather than the point of view chosen for them by the director of the film. The choice of shot sizes, camera angles, camera movements, and actors' positions versus the camera is now all up to the viewer. Moreover, it remains undetermined until the moment of viewing. In consequence, the watching process can no longer be described as passive. Every time the volumetric film is watched, or rather interacted with, the viewing is as different as would be the viewing of a traditional film that was reedited before every screening. The viewing process becomes the mode of interaction with the volumetric film, and the viewer takes on the role of the cinematographer and the editor.

Conclusion

While volumetric filmmaking is in its infancy, with only a handful of completed films, the technologies required to democratize and popularize this new-in-kind storytelling medium are becoming more and more accessible to independent filmmakers and visual artists. It can be expected that the volumetric filmmaking, once the technology matures, will find many applications in entertainment, education, communication, and many other domains.

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World of Tanks, MMO Strategy Freemium Game

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Synonyms

MMO, Multiplayer game, Strategy game

Definitions

MMO = Multiplayer online game is a multiplayer game designed to be played online

Multiplayer game = A game that is designed for multiplayer mode where two or more players are expected throughout the entire gameplay

Strategy game = A game that emphasizes the use of strategy to win

Freemium = A portmanteau of the words "free" and "premium," a freemium is a free-to-

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play software for which fees are charged for additional features and services

Esports = Competitive video game tournaments

Introduction

World of Tanks is a freemium team-based MMO involving armored tank combat. Developed by Wargaming, World of Tanks was released in North America on September 6, 2011.

Gameplay

World of Tanks is a team-based, action-packed, combat strategy game involving tanks from several different nations to fight against each other until one prevails in victory. The standard game mode within World of Tanks is known as "Random Battle." These battles consist of 15 versus 15 battles in which your objective is to either eliminate all opponents or capture the enemy base. Depending on the game mode, matches can last from 10–15 min, ending in a draw if one team does not eliminate the other.

World of Tanks is on desktop, consoles (e.g. Xbox and PlayStation), and mobile phones (World of Tanks, 2022). There are various game modes within World of Tanks such as Skirmishes, Ranked Battles, Training Rooms, and Special Battles. Skirmishes are oriented toward clan coordination in which you can battle just like normal random battles, but it is more of a team effort as you are playing with clan members rather than random players. Ranked Battles is a game mode offered periodically that allows players to compete against each other to gain chevrons. These chevrons allow you to advance throughout several divisions. After completing all the divisions, you will be assigned a rank of bronze, silver, or gold based on performance during division completion. Rewards vary depending on the rank you have earned. Training Rooms allow you to create a private match with friends, clans, or anybody to scrimmage, explore, or develop strategies for fighting. These rooms can be used for anything. Lastly, Special Battles are for tournaments and other Wargaming-sponsored events. Special Battles are typically available after you have participated in some sort of competitive events.

Playable characters

The game contains over 700 different tanks from many nations including Britain, China, Czechoslovakia, France, Germany, Italy, Japan, Poland, Russia, Sweden, and the USA (*General Guide: World of Tanks* 2022). These vehicles are rated using a tier-based system to pair them all up equally on the battlefield. There are also multiple tank classes to help categorize tanks. These classes are as follows: Heavy, Medium, Light, Tank Destroyer, and SPG (Self-Propelled Gun). Heavies are designed to be a more armored class that is meant to be in the front of the brawl. Light tanks tend to be used for spotting out maneuvering opponents with their incredible vision and speed. Medium tanks come up somewhere in the middle, being a hybrid of heavy and light classes. Tank Destroyers are your high-damage dealer tanks, bearing some of the most lethal armaments in the game. Finally, there is the SPG class which operates completely different in comparison to the other classes. SPGs are a long-range armament designed to be more of a support vehicle from afar. The tank shown in Fig. 1 is a light tank. This light tank is quite different from other tanks within the game because it utilizes wheels instead of tracks. This allows the vehicle to excel in speed and maneuverability.

There are many additional features within World of Tanks that allow for the enhancement and personalization of tanks. Some of these enhancements include crews and their trained skills, equipment, field modifications, ammunition, and camouflage. These upgrades and enhancements allow you to customize your tank to fit your playstyle and needs, allowing you to become more impactful on the battlefield.

Within World of Tanks there are also several currency systems such as Silver, Gold, Bonds, and

World of Tanks, MMO Strategy Freemium Game, Fig. 1 A light tank

Free Experience. Silver is the standard currency within the game. It can be earned from battles and challenges, and it can be used to purchase new vehicles, equipment, ammo, and more. Gold is the premium currency within World of Tanks. This is mainly used for retraining crews to operate different tanks, converting experience into free experience, purchasing premium vehicles, and demounting equipment. Although this premium currency can be purchased with real money, Gold is earnable through tournaments and challenges. Bonds are a very prestigious currency in World of Tanks, and they are earnable only in game through performance and challenges. Bonds are often given as a reward for performance in competitions and other high-level events, but they are also earnable in small amounts after every random battle. Bonds are mostly used to purchase special vehicles and bond equipment, which is the best equipment in the game (aka War bonds) (*World of Tanks War Bonds* 2022). Lastly, Free Experience can be earned slowly through matches or by converting normal experience earned in tanks with Gold currency into free experience. Free Experience can be used to unlock new tanks, modules, field modifications, and more – allowing players to experience a new vehicle without the tedious process of playing in a stock or underequipped tank.

Reception

After more than 10 years since the debut of World of Tanks, Wargaming claims that they have had over 60 million registered players and a peak concurrent player count of 1.1 million (*World of Tanks Announcements* 2022). However, the Russian and European game servers are much more populated than the North American server. Population on the North American server can typically be found around 10–20 thousand depending on the time of day.

Esports

World of Tanks debuted as an esports game as early as 2012. However, the only official World of Tanks esports tournaments were the

World of Tanks, MMO Strategy Freemium Game, Fig. 2 Professional team Natus Vincere "NAVI" winning the 2017 World of Tanks Grand Finals

Wargaming.net League, which took place over several regions including North America, offering a prize pool of $300,000 (Griffin 2014). While it was entertaining to many players, the competitive league did not draw as much attention as Wargaming had imagined and it has since been shut down. Figure 2 shows the professional team Natus Vincere "NAVI" winning the 2017 World of Tanks Grand Finals. The 2017 Grand Finals were the last year in which Wargaming.net League held the competitive league.

Although there is no longer an official Wargaming-sponsored esports league, Wargaming continues to host several large tournaments throughout the year, rewarding in-game currency or monetary prize pools.

Conclusion

Overall, World of Tanks is a fun and addicting spin on team-based fighting games. World of Tanks offers strategic combat, including legendary historical tanks from real life, to create a fun and entertaining battlefield for players to fight among each other.

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World of Warcraft, a MMORPG with Expansions

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Synonyms

MMORPG

Definitions

MMORPG = A Massively Multiplayer Online Role-Playing Game (MMORPG) is a video game that combines a role-playing game and a massively multiplayer online game.

Expansion = Extra purchasable content for a game released after the launch of the game. Each expansion can bring new characters, environments, and gameplay to the game.

MMORPG

World of Warcraft, often abbreviated as *WoW*, was released on November 23, 2004. The game was developed by Blizzard Entertainment for Microsoft Windows and macOS. It is the fourth game in the *Warcraft* series, although the first to be an MMORPG. It was given a Teen rating by the ESRB. *World of Warcraft* operates on a subscription service where players purchase times they can play in one-month, three-month, or six-month intervals.

WoW is an MMORPG that puts players into the world of Azeroth. *WoW's* core audience at the start were those who played the previous Warcraft games but branched out to many types of gamers as the game's audience grew larger. *WoW* currently has 12 playable classes, each with multiple different specializations that greatly vary the gameplay. Leveling through *WoW*, players don't encounter many enemy mechanics other than the odd spell and mob auto-attacks, however, as they advance through levels they also gain new abilities every level or two, and dungeons, as well as end game raids, have a lot of mechanics. The actual gameplay of each character is hotkey-based combat where players push keys on their keyboard to make their character do things. Although none of this is new now, it set the standard for MMORPGs (Thursten 2014) *WoW* has a reputation for a good soundtrack, whether it's a sad character piece or epic boss encounter music. There is also lots of variation in the music from zone to zone, and many have fond memories from the game's launch of playing through the initial levels and hearing the music (Messner 2020).

Expansions

WoW takes place on the planet of Azeroth mainly but also features planets such as Dreanor and Argus. The initial story of *WoW* has each player being a random adventurer, slowly growing in strength as they journey their way to the max level, at which point they would start going after and defeating strong "boss" mobs. After the initial variation of the game ended, Blizzard started making expansions that completely overhauled the classes, added a whole new leveling area, raised the level cap, and added in new leveling and end game content. The expansions also came with a new story, mostly revolving around large threats to the world, but never forgetting the foundation of the Warcraft franchise, which is the idea of the Alliance faction versus the Horde faction and the characters involved. *WoW* features a classic RPG leveling system, with the current cap being level 120. Although *WoW* has largely maintained the same visuals over the years, there have been

changes made to character models, improvements to the art style, and every new expansion comes with new environments that helped vary up the gameplay and the world. The gameplay changed in every expansion, from the slower pace of the original to the faster pace of today. *WoW*'s gameplay is drastically different from when it launched.

Interface

WoW's interface starts with a single action bar in the bottom right to hold spells and abilities, to the right of that is a range of buttons, including the character screen and the help menu, to the right of that is the bag slots where the bags a player has on them and how much space is in them. In the upper left is the health and resource bar, and finally in the upper right is the mini-map. There is also the option of adding in three more action bars if players run out of space (Fig. 1).

WoW is one of the most well-known games ever released, and scored very highly by fans and critics alike. It is also one of the most played games of all time (Fbalestra 2015).

Controversies

One of the biggest controversies in the community was the final raid of the Cataclysm expansion (Wolfshead 2011), which had a small eight boss count, and ended with two of the most hated raid fights in the game's history. Another controversy was the announcement of the Mists of Pandaria expansion (Cirino 2012), this was controversial because many players thought it was a bit weird to go from killing a giant dragon that wanted to destroy the planet, to fighting alongside a bunch of panda people and learning about unimportant things like farming and peace. Since the day of launch, *WoW*'s biggest weakness has been its servers. The issue is that the servers were made for a game that would cap out at about 200,000 players. Considering that *WoW* peaked at around 12 million players, it's easy to see why even to this day, despite the fact that Blizzard has spent more than a decade trying to fix it, if a large group of players gets on a busy server, the game will start to have issues.

Similar games to *WoW* include *Everquest* and *RuneScape*. Both of these games have similar designs and concepts (especially *Everquest*), but

World of Warcraft, a MMORPG with Expansions, Fig. 1 World of Warcraft interface.

WoW definitely set itself apart with its better graphics and less punishing systems.

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World Representation in Artificial Intelligence

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Synonyms

Knowledge; Knowledge representation and reasoning; Spatial reasoning

Definition

World representation is used as an umbrella term to encompass any method allowing the Artificial Intelligence (AI) agents to know about the world they are operating in. This includes, but is not limited to, navigation data, knowledge representation, and spatial reasoning, to name only a few. Globally, these techniques revolve around organizing the information defining a virtual world into specific data formats, designed to be easy to process for in-game AI agents. The agents then access that data and process it to accomplish the behaviors or computations needed by the game.

Introduction

Video games allow human players to immerse themselves in virtual worlds. The level of interactivity of these worlds varies from one game to another, but in all cases, players can rely on their own senses to explore and interact with the virtual environment of the game.

AI agents, on the other hand, do not have access to the same perception and reasoning skills as human players. Emulating human senses is a possibility, and is especially common in robotics AI, where robots will use sensors to recognize the environment around them. However, in the case of video games, this process is too costly in terms of both calculation and memory. This makes it unsuitable for game AI agents, which can be many to share the same processing power. As an alternative, the solution is to use dedicated formats of data to represent elements of the virtual world. The goal of these formats is to be efficient to access and easy to process for AI agents. The organization of that data is what makes up world representation.

This chapter will present an overview of multiple techniques that are used for world representation. First, we will cover environment knowledge, going from navigation data to interactive objects, which allow an agent to navigate in the environment and interact with elements contained in it. We will then move on to spatial reasoning, which involves more complex computations on the environment data in order to take some intelligent decisions with regard to an environment's layout. In opposition to globally shared environment data, we will then cover individual agent knowledge, which comprises perception and some forms of imperfect knowledge. Finally, we will go over multi-agent knowledge, which is necessary to achieve intelligent behavior for a team of multiple characters.

Environment Knowledge

In order to be able to navigate and interact with an environment, the first step for AI agents is to know how that environment is structured. Navigation data allows them to know about navigable terrain, move around without hitting obstacles, and find suitable paths from one location to another. In addition to the navigation data, environment markup information allows the AI agents to achieve advanced traversal and interact with the objects.

Navigation Data

Navigation data is an abstract representation of the game world, containing only the sections that can be navigated on. The specific representations can vary, but internally all of them boil down to a graph between different locations. A pathfinding system can then search the graph to compute paths between positions in the game world. This is ultimately what allows the AI agents to know how and where to navigate through the game world. This section will focus on the data representation for 2D and 3D navigation.

2D Navigation

2D navigation data is used to represent walkable surfaces, such as floors. Common representations include navigation grids, waypoint graphs, or navigation meshes. These will be covered in this section.

A navigation grid divides the game world into a grid composed of cells of a fixed size (Yap 2002). Each cell is marked as either blocked or unblocked, based on whether or not it is possible or not for an agent to navigate on the terrain in that cell. Navigation is then achieved by finding paths that go through connected cells.

Waypoints graphs represent the game world as a graph of connected points. Waypoints are placed or generated in the world, as a way to discretize the navigable surfaces. A connection between two waypoints, means there is a way to navigate directly from one to the other (Liden 2000). Each waypoint represents a valid position where an agent can decide to go. Navigating through a waypoint graph is then done by going from one waypoint to another through the connections between them.

Navigation meshes are probably the most common navigation representation in modern games. They divide the 2D navigable space as convex polygons. Each polygon is a node in the search graph, while common edges between two polygons represent an edge in the graph (Snook 2000). Navigation meshes are more complex than navigation grids or waypoint graphs. Because navigable terrain is divided as convex polygons, these polygons can represent areas of variable size and shapes. Navigation meshes can be authored manually or generated automatically by analyzing the collision data of an environment.

3D Navigation

While the navigation data in most games will be limited to 2D navigable space, some games require 3D representations, for movement such as swimming or flying. The number of available axes for motion is the main factor. Additionally this can also be a viable way of representing sound propagation, as mentioned in section "Perception". Representations for 3D navigation include navigation grids and sparse voxel octrees.

Navigation grids work the same way in 3D than they do in 2D, with the exception that a cell is a cube instead of a square. The whole environment can be represented using blocked or unblocked cells, similarly to 2D grids. Because of the nature of 3D space, the number of cells quickly grows, meaning that this can be very memory intensive. The main challenge revolves around finding a way to make the representation more sparse (Sturtevant 2011).

Armored Core V uses procedural generation to create their 3D navigation grid. The game space is filled with a large number of cubes, which then needs to be reduced. This is done through simulated annealing, which combines adjacent cells together by keeping as big cuboid shapes as possible (Okamura 2011).

As an alternative to 3D navigation grids, sparse voxel octree can be used to represent the 3D space. Instead of a grid, each cube of space is

divided into eight children, recursively until a minimum size, and organized as a tree. This results in a representation that is more optimized than a simple 3D grid (Brewer 2017).

Choosing a Representation

Ultimately, all of those formats are a valid way to represent the space in which an AI agent will need to navigate. Selecting the best representation will come down to several factors, such as memory, performance, ease of use, and the type of environment the game will use. Articles such as Sturtevant (2013) and Tozour (2004) explain in detail the advantages and shortcomings of each approach.

Environment Markup

Navigation data allows agents to have information about where they can navigate in their environment. However, games often have complex environments that require advanced interactions in addition to moving around. In those cases, environment markup can be used alongside the navigation data in order to provide information to the AI agents about how they can interact with the environment. This can be used for advanced navigation such as doors or ladders, to find good positions or covers during combat, or to interact with objects in the environment.

Advanced Navigation

There are many ways in which a game level can be composed of navigable areas which are not directly connected to one another. AI agents can go from one area to another by jumping, going through doors, or other types of interactions (Hancock 2002; Reed and Geisler 2003).

These types of connectivity require setting up some environment markup to indicate the connected positions from one area to another. Such markup needs to contain some information detailing the type of interaction. When pathfinding, it becomes possible to know a connection exists between two different areas. Upon reaching that connection, based on the type of interaction necessary, a special behavior can be performed to reach the desired area.

Tactical Positions

Many games involve some form of combat, which tends to depend on finding correct tactical positions from where to fight. A way to find good tactical positions is to have suitable candidate positions as part of the environment markup. A straightforward way to do this is to manually add some markup in the environment where there are suitable tactical positions.

A more clever way to represent tactical positions might be to reuse navigation data. This is one of the strengths of waypoint graphs, as tactical information can be embedded inside the waypoints to allow them to become valid tactical positions (Liden 2002).

As this type of markup editing can easily become time sensitive, methods that can automatically generate tactical positions are an interesting alternative. As this does not represent the environment markup, this will be covered in section "Terrain Analysis."

Covers

A good tactical position often involves hiding or covering behind a solid surface, rather than finding a position in plain sight. For this reason, cover is a very common game ingredient when it comes to game in AI. Cover selection is resolved using similar selection algorithms than tactical positions.

However, cover markup in itself will be different because more information is necessary (Darken and Paull 2006). Covers are tied to physical objects or parts of the environment, which give protection in specific angles and directions. They can also permit or not to fire in certain directions while partially hidden, or necessitate some advanced navigation in order to reach or enter them.

Smart Objects

Any other type of interaction will generally involve some external objects that can vary from one game to another. In those cases, smart objects (Kallmann 2001) are the standard solution. These objects are called smart because they contain the information about how the character should

interact with them, via some form of script or internal data. This allows for some flexible and scalable interactions where an AI agent can detect interactive objects around them, and figure out how to use them by interfacing with the object.

Spatial Reasoning

With tactical positions and cover object markup, section "Environment Markup" introduced the notion that in addition to knowing how to navigate and interact with their environment, AI agents need to make intelligent decisions about where to go and what to do once they get there. Up to now we have covered methods to achieve this which involve annotating a game level with additional information. Spatial reasoning, on the other hand, regroups techniques that aim to identify information about the environment through computation. This section will cover multiple approaches to spatial reasoning.

Influence Maps

Influence maps are used to identify areas of the game world that are subject to a certain influence. In this context, influence is an abstract measure of a game mechanic such as threat value, territory ownership, or any other type of information that can be tied to space and change over time. Influence can then be used in order to know how good a given position is or in order to find the best position to do something (Tozour 2001).

The first step to building an influence map is to discretize the environment into smaller areas. The most straightforward method is to divide using a grid approach, similar to the navigation mentioned in section "2D Navigation." Each cell in the grid has a given value of influence at a given time, which can be accessed by the AI as a source of information.

In order to compute the value of influence at a given location, influence is propagated from various sources. For instance, when computing threat influence, influence can be propagated from an enemy's position in a radius around them, with a given decay function. Propagated influence values can then be added (or subtracted for opposing influences) to result in a final value at each position. Because game worlds are constantly changing, influence values need to be recomputed periodically.

The main downside of influence maps is that they tend to be expensive computation wise. Potential solutions include using a continuous, rather than discrete, approach to reduce the amount of computations (Lewis 2015), or cleverly combining precomputed influence map templates to efficiently obtain results (Mark 2015).

Terrain Analysis

Terrain analysis refers to any technique aiming to reason about the terrain in a game in order to find certain interesting properties. The goal is generally to find some positions that are good to go to perform certain types of actions, or in the opposite, which are good targets for certain types of actions. As the applications for terrain analysis are many, this section will only cover some of them as examples.

It is important to note that in all of the following examples, the amount of computation required to obtain results is quite significant. This means terrain reasoning is usually too expensive to perform while the game is running, and is instead done during a preparation phase using a level's geometry data. The pre-computed results are then stored in a specific data format that is easily accessible during the game.

Identifying Choke Points

Choke points make for excellent positions for the AI agents to plan an ambush, or defend some territory from an external invasion. However, finding choke points requires some deep understanding of the level's layout and navigable space. Perkins (2010) describes an algorithm to find choke points based on region adjacency.

Starting from the obstacle polygons in a level, this technique aims to divide the level into regions. A region is defined as a navigable space that is not blocked by an obstacle. The goal is then to identify choke points, which if blocked, would either merge two obstacles together, or prevent one region from being reachable by another.

Finding Combat Positions

Section "Tactical Positions" went over not only on the idea of annotating levels with tactical position data but also on the necessity of determining what positions are good attack positions. Liden (2002) describes methods to use a waypoint graph to automatically find tactical positions.

The idea is to reuse the waypoints that are used for navigation as a source of information to find tactical positions. Because all the potential positions are known ahead of time, it is possible to precompute information about them, such as the visibility from one point to another. This information can then be used at runtime to find positions that are protected from one another, or to execute flanking tactics.

Finding a Sniping Position

In shooter games, some positions are clearly better than others to engage in ranged combat with enemies. Especially, in the case of snipers, good positions involve having visibility towards other parts of the map, while also being difficult to reach. der Sterren (2001) describes the steps to find good sniping positions using those types of criteria.

A sniping position is essentially a specific case of a combat position. Thus, once again, reasoning using waypoint data is possible. The different qualities that make a good position can be expressed as numerical values, and obtained through the waypoint graph data, such as luminosity, line of sight to another waypoint, and so on. A score can then be computed for each position, and the highest rated positions represent good sniping positions.

Finding Covers

Covers are an especially complex, specific case of combat positions. Paull: Online Offline cover finding presents methods to find covers based on waypoint data, cover data and runtime processing. For each agent, by evaluating a fixed amount of candidate waypoint positions around the agent, these candidate positions can be ordered based on visibility, and ability to peek-out.

Tactical Query Systems

As a follow-up to terrain reasoning, modern game engines have been introducing tactical query systems as an alternative to find positions during a game's execution. Popular examples of these systems include Crytek's Tactical Point System (Jack 2013) or Unreal Engine's Environment Query System (Zielinski 2013).

The resolution of a query involves multiple steps. First, a region of the environment will be sampled to generate a large number of candidate positions to be evaluated. Then each position will be evaluated by tests aiming to filter and score the candidate points. The goal of filtering is to eliminate the candidate positions that are absolutely unsuitable, such as a point inside of a wall, or a point in a different room. The points that are not filtered will be attributed a total fitting score based on the criteria evaluated. A position receiving a high score might be easy to navigate to and offer a good tactical advantage. Finally, the best, or several of the best positions can be selected as the result of the query. More details about the steps of resolving a query can be found in Johnson (2017).

Imperfect Individual Knowledge

Till date, this chapter has covered different approaches to give the AI agents global information about the game world. However, in order to have credible AI agents, it is often common to have them know only about subsets of the environment. Similar to real humans, these AI agents should only be aware of the parts of the environment they have been exposed to. This is called imperfect individual knowledge.

Imperfect individual knowledge uses an architecture modeled on the human brain. As a first layer, AI agents have a form of perception similar to human senses, in order to identify what they are able to detect or not. Perceived information is then stored in a memory layer. That memory becomes the knowledge base allowing the AI agents to take decisions (Isla et al. 2001).

Perception

Even though humans have access to five senses, only three of them are commonly used to model AI perception. Sight is used to see elements of the environment, hearing is used to react to noises, and touch is used to react to collisions.

Vision is mainly modeled using ray casting from the agent's position to some other entities in order to test if they are being detected. Because raycasts are expensive, this is usually combined with a vision detection volume. Only entities currently in the detection volume will be tested for raycasts, thus reducing the computation cost. Different volumes of different shapes can be alternated or combined depending on the game's needs (Walsh 2015).

Depending on the type of game, hearing can be simple or complicated. For some games, hearing can be modeled using only distance tests. Hearing capacity is modeled given a certain range, and any sound generated inside that range will be heard by the AI agent. Other types of games will require a more accurate model of hearing. A way to achieve this is to reuse the concepts of 3D navigation to represent hearing (Walsh 2015). In that case, hearing is resolved by testing for 3D reachability from the source of the sound to the agent.

Compared to sight and hearing, touch is normally fairly easy to implement. Since most games already contain a physics engine, that engine's collision detection can be reused to model touch. By reacting to collision callbacks, an AI agent can react to something touching them, based on the source of the contact.

Memory

Information that is perceived can be stored in a memory. From there on, the agent will be able to reason based on the content of that memory, rather than on information that is globally available from the game world. This leads to agents working with imperfect knowledge based on what they have perceived, which is closer to how humans behave.

Probably the most currently common format to store an AI agent's working memory is to use a blackboard (Isla and Blumberg 2002). As the name implies, a blackboard is a shared repository of knowledge, where variables can be added, modified or read by any AI system. This allows easy access to any information the AI should currently know, while also reducing strong coupling between different AI systems. Any perceived information can be added to the blackboard, to be used at the time of decision-making.

Stimulus Knowledge

Section "Perception" covered different types of perception, while section "Memory" explained how detected information can be stored in memory for an AI agent. However, detecting events that happen in the game is only a first step. With a lot of characters doing different things, a player affecting the world, there can be a lot of stimuli being detected by the AI agents. For this reason, some form of filtering and prioritizing is generally necessary to make sure agents are not overwhelmed by the amount of stimuli, meaning spending too much performance on detection, or reacting and acting with regards to stimuli in a way that seems unintelligent.

Simple examples of filtering involve ignoring stimuli from allied sources, or ignoring some stimuli based on the current level of alert. Additionally, some things happening in the game are definitely more important than others, meaning that there must be some sort of priority system. Miles (2013) and Welsh (2013) feature good examples for both filtering and prioritizing.

Probability Occupancy Grid

For games where fighting against enemies is a core element of gameplay, proper consistency of threat management data is primordial. AI agents must behave according to the information they have detected, as threats are detected, then lost, and discovered again.

A good technique to model credible search behaviors based on accurate data is to use a probability occupancy grid (Isla 2006). Probability occupancy grids share some similitudes with influence maps, covered in section "Influence Maps," as they rely on propagating data along a grid representation of the world. When a threat goes from being detected to undetected, the last known position can be retained on the grid. Then,

as time passes, the potential displacement of the threat can be propagated on the grid from the last known position. This allows the modeling of plausible candidate hiding positions that can be investigated.

Agent Coordination

Section "Imperfect Individual Knowledge" covered imperfect knowledge in the context of an individual agent acting alone. However, games will most likely contain more than one AI agent, and AI agents will need to consider the information about each other. When other agents are enemies, threat data as covered in section "Probability Occupancy Grid" will usually be sufficient. In the case of AI agents acting as a team, some form of information sharing is necessary to make them appear to work together.

Orchestrated AI

One approach is to use an orchestrated AI (der Sterren 2002). In this situation, all decision-making relating to what the AI agents should do as a group is the responsibility of a separate AI module. That module will either use perfect knowledge or the union of all agents' imperfect knowledge to determine where agents should position themselves or which member of the group should be selected to do a specific action.

There are multiple ways to communicate between that group AI layer and individual agents. The group can give direct commands to the individuals, or update their individual knowledge in some way to allow them to take the proper decision on their own based on what was decided by the group (Reynolds 2002).

Emergent AI

On the other hand, agents can take all of their actions on their own. In this situation, they will need to know about what information the other agents have, in order to maintain at least an illusion of coordination between agents.

A very simple solution is to reuse the concept of blackboard from section "Memory". In addition to having an individual blackboard to store an agent's current knowledge, an additional blackboard can be used to share knowledge between agents. Each agent can then add the information they want to share to that blackboard, and everyone can access it to have the most up to date information.

Another solution is to use a trigger system (Rabin 2002) to propagate the information to agents. Triggers can be set up to send events on reaction to some actions the player is taking, some changes in the environment, or simply be sent deliberately from one AI agent to others. Once a trigger happens, each agent can decide what to do upon receiving the information. It is possible to react immediately upon reception, or to store the information in some form of knowledge representation in order to take a decision about it later.

Discussion

This chapter provided an overview of many different techniques that can be used to give AI agents information about the environment they are evolving in. This section discusses in more detail the current usage trend of these techniques for modern games, as well as what kind of challenges can be expected for future games when it comes to world representation.

A good portion of the techniques covered in this chapter are standard and well spread among games. For example, close to all games feature some sort of navigation, and thus will make use of navigation data. It is now very common to have interactive objects in game environments, which can be implemented as smart objects. Most modern games aim to have credible AI that does not appear to cheat, thus relying on perception and individual knowledge. These are example of techniques that have been used for a long time, are well understood and can be added to any game that needs them without too much trouble.

On the other hand, the other techniques are less frequently used, which can be explained by multiple factors. Finding choke points makes a big difference for a strategy game, but may not have such a big impact on other genres. Influence maps add an additional layer of information to the

game, but come with a cost both in terms of development time and performance. A probability occupancy grid adds some amount of intelligence to an AI performing a search, but may not be needed outside of stealth games. The richness of cooperative behavior using squad AI can be enticing to have an impressive AI, but managing the complexity between group and individual AI can quickly become complex. These are examples of techniques that are more specialized, and come with a certain cost, meaning they should only be implemented if there is a strong need for it.

These less-used techniques highlight the fact that there is rarely one single optimal solution when it comes to game AI. Developing and integrating a world representation technique incurs some costs in terms of both development time and hardware resources, such as processing power or memory. Choosing the appropriate world representation techniques to use should be done by considering what is needed for the game being developed.

Regarding newest and future development for world representation in games, two different factors are having an impact. On one hand, hardware is getting more and more powerful, meaning that problems that were limited by performance issues can be more accessible. On the other hand, games are getting bigger and more complex, meaning that the amount of information to be tracked is bigger than ever.

Access to more performance intuitively makes expensive techniques more accessible. However, the biggest impact is on techniques such as navigation data generation or terrain reasoning, which are traditionally done as a preparation pass to output precomputed data that will be used by the game. Access to more performant hardware means that such techniques can gradually migrate to runtime solutions. Precomputed navigation data is still the norm, but runtime navigation data is becoming more common. Similarly, tactical query systems can perform at runtime some of the operations that were initially reserved to terrain reasoning.

At the same time, games are scaling both in size and complexity, so performance remains a limitation. However, these limitations tend to manifest in different ways now that techniques are evolving. Rather than relying on raw processing power, games are being clever with resource management by using systems such as multithreading, asynchronous updates and streaming. Naturally, the central nature of such systems means that there is also an impact on world representation. Systems should now handle objects being loaded or unloaded because of streaming, as well as information being accessed concurrently.

Conclusion and Discussion

This chapter presented many different techniques allowing the AI agents to know about the environment they operate in, even though they do not have access to the same senses and reasoning as humans do. Navigation data combined with environment markup allows them to know how to navigate in the environment, as well as how to interact with it. Spatial reasoning allows them to understand the spatial layout of an environment, and to take intelligent decisions based on it. Imperfect knowledge allows individual AI agents to act credibly based on the information they have perceived themselves. Finally, knowledge about other AI agents allows them to have some mutual awareness and perform some coordinated actions.

Some of these techniques are broadly used, others are more specific, meaning understanding what problems they solve is primordial to choosing which techniques to use. As technology progresses, some techniques that were difficult to implement because or performance constraints become more available, even allowing some runtime evaluation techniques. Simultaneously, games continue to become more complex, meaning that performance is still an issue, and techniques have evolved to support streaming and multithreading. As games themselves will certainly continue to evolve, new needs for world representation will continue to appear leading to a corresponding evolution of world representation techniques.

Cross-References

- ▶ Computer Games and Artificial Intelligence
- ▶ Motion Planning in Computer Games
- ▶ Overview of Artificial Intelligence

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Z

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